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Metal Progress

JULY 1945

Carbon Restoration

(SKIN RECOVERY)

OF DECARBURIZED STEEL SURFACES

'SURFACE' ACHIEVEMENTS IN THE SCIENCE OF GAS CHEMISTRY AND HEAT TREATING

*

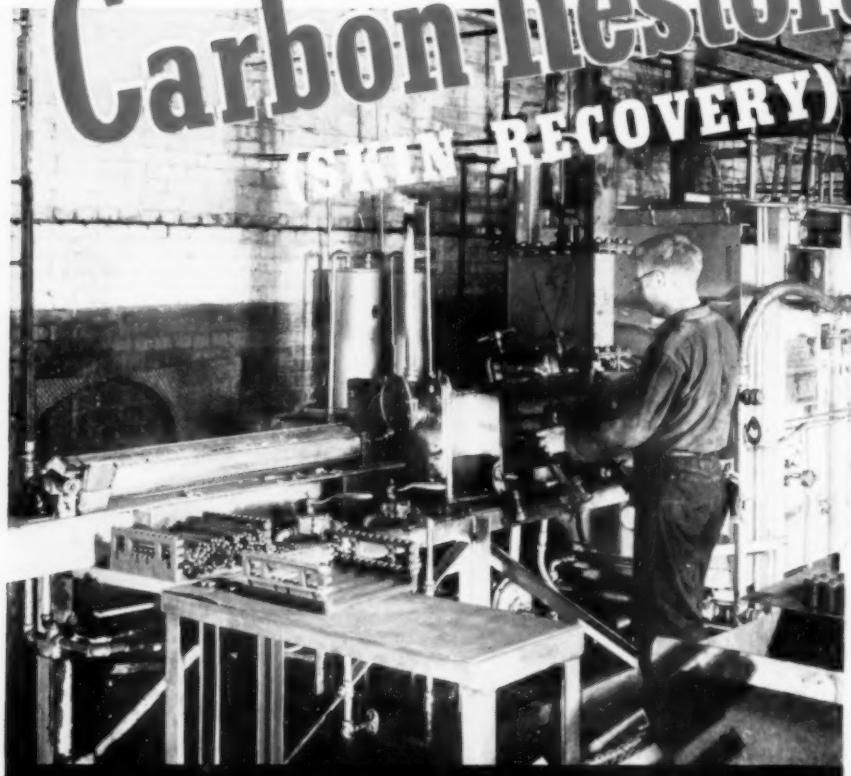
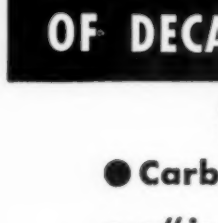
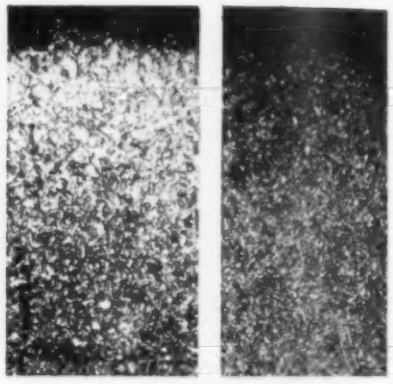


Photo above shows 'Surface' continuous, pusher-type furnace used for carbon "skin recovery" treatment.

● Carbon Restoration or "Skin Recovery" is a simple controlled-atmosphere process based on the principle of carbon pressure balance...applied today to various engineering steels.



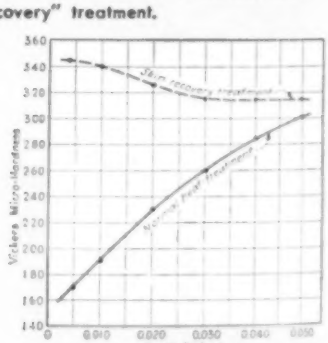
This process is another 'Surface' development to come from extensive research in the Science of Gas Chemistry. Write for reprint "Skin Recovery for Decarburized Steel Surfaces" for further details of the process and application.



ONE EXAMPLE

Left: An SAE 4140 forging showing decarburized edge after normal heat treatment.

Right: Same SAE 4140 forging after "Skin Recovery" treatment.



Hardness vs. depth readings on SAE 4140 steel forgings before and after "Skin Recovery".

'Surface'

* **SPECIAL ATMOSPHERE, RADIANT-TUBE FURNACES FOR:** Gas Carburizing and Carbon Restoration (Skin Recovery), Clean and Bright Atmosphere Hardening, Bright Gas-Normalizing and Annealing, Dry (Gas) Cyaniding, Bright Super-Fast Gas Quenching, Atmosphere Malleableizing, Atmosphere Forging, and Specific Effects upon Metal Surfaces.

SURFACE COMBUSTION CORPORATION · TOLEDO 1, OHIO

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By Joel C. Carpenter
Captain, Ordnance Dept.
U. S. Army
Cleveland

Metallurgical Problems in the Manufacture of Seamless Gun Tubes

LATE in the fall of 1941, before the United States entered the war, it became apparent to the War Department that some new method should be developed for producing cannon tube forgings—a method which could augment the then existing gun forging capacity.

The conventional method of producing cannon tube forgings had been to reduce ingots by cogging or press forging to the rough outside shape and size of the gun desired, and then bore out the center. However, the demand for aircraft, tanks, trucks, and other vehicles, as well as shot, shell, armor plate, and the increasing naval program was using nearly all of the available forging capacity in the country, and in addition had mortgaged the future production of heating and forging equipment for some time to come. Unless some method could be devised wherein existing facilities could be used to produce gun forgings, there was little possibility of meeting the contemplated production schedules. Centrifugal casting was developed to the point where it could take a part of the load, but all existing centrifugal casting installations were already scheduled to capacity, and it would take a considerable amount of time to build more and get them into production, to say nothing of finding plants that could produce the heavy and specialized equipment needed for them.

The solution of the problem was to find a new method for producing gun forgings quickly and which would not require additional forging equipment. It was at this time that the Cannon Section of the Artillery Branch, Office of the Chief of Ordnance, decided to experiment with seamless steel tubing for gun tubes.

One of the foremost alloy steel and seamless tubing producers in the United States was asked to undertake this developmental problem. The first seamless steel tubes produced were for the 37-mm. gun, and were made from A.I.S.I. 4135 and 4335 steel. They were pierced on a conventional piercing mill, cut to length, and the breech end upset. These rolled and upset tubes were then heat treated at Watertown Arsenal and sent to Watervliet Arsenal for machining. Finished gun tubes were proof tested at Erie Proving Ground, with results comparable to guns made by existing and more conventional methods.

With this experience as a background, and as an indication of the possibilities of the process, further work was undertaken, and a number of 40-mm. and 75-mm. gun tubes were made of seamless tubing. Proof tests continued to indicate comparable results with guns made by the regular forging process.

The results of this development work were sufficiently favorable to warrant the Ordnance Dept. to plan for large scale production. This meant that large quantities of gun tube forgings could be produced without the necessity for extra bloom heating and forging capacity. It meant that all of the hot reduction, together with the necessary heating, could be done with conventional steel mill furnaces and the rolling and piercing mills, which could be scheduled for additional capacity although already operating at a high rate.

While it was accepted practice to melt gun steel in electric furnaces, melting capacity was very critical at that time; it was therefore decided that openhearth steel could be used, provided proper care was taken in the melting and pouring practices. Many of the problems encountered in the program were undoubtedly accentuated by the fact that, generally speaking, the cleanliness

Fig. 1 — Rolled 8-In. Rounds Are Cut to 7-Ft. Lengths, Reheated in Inclined Hearth Furnace, and Pushed Endwise onto Transfer Table, Enroute to Piercing Mill. All photos courtesy Steel and Tube Div., Timken Roller Bearing Co.

of openhearth steel does not equal that of electric furnace steel.

Early in 1942 the War Dept. bought and equipped a plant expressly for the production of seamless gun tubes. This plant was operated by a contractor, with an Army Ordnance officer in residence as the War Dept. representative. During the approximately two years which this plant operated, the following quantities of gun tube forgings were produced:

More than 40,000 40-mm. gun tubes.

More than 35,000 75-mm. gun tubes.

Small quantities of other medium caliber gun tubes, such as 57-mm., 76-mm., and 105-mm.

Description of Process

Several American plants producing alloy steel tubes furnished the pierced tubing. The steel was melted and cast in big-end-up molds with hot tops. Ingots were rolled into blooms, and then into round billets; after slow cooling, the billets were reheated and pierced into heavy walled tubes in conventional piercing mills. After a sizing pass the tubes were slow cooled, marked and shipped to the gun plant where they were cold sawed to length.

Next, one end was heated to forging temperature in specially designed Tocco high frequency heating units, and a heavier breech upset by a large forging machine or upsetter of conventional design.

The rough formed gun tubes were then hung on an overhead conveyer by means of a bail welded to one end, and conveyed through a normalizing furnace. This treatment was followed by a trip through a second furnace where they were heated to quenching temperature. The quench was in water for a controlled time and temperature, including a forced quench up through the bore of the tube.

Following the quench, the tubes were conveyed, still in a vertical position, through a tempering furnace. After cooling, the tubes were pickled, straightened, and test disks sawed from both ends, thus bringing the tubes close to working length.

The tubes were then rolled horizontally through a stress-relief furnace, operating approximately 100° F. below the tempering temperature. After cooling they were inspected for surface (outside and inside), eccentricity and straightness, and were then stamped and shipped to the plants where they were to be machined.

Machining of the seamless gun tube forgings was done at various arsenals and contractors' plants, approximately as follows:

1. Rough bore.
2. Center, and rough turn O.D.
3. Finish bore and hone I.D. to size.
4. Inspect I.D.
5. Machine O.D.
6. Rifle I.D. by broaching.
7. Inspect I.D. rifling.
8. Finish machine outside of gun tubes.
9. Final inspection.

Metallurgical factors which influence the quality of finished gun tubes are:

Metallurgical Factors

1. The effect of chemistry upon the quality of the steel.
2. Quality of the steel as affected by the melting, deoxidation and pouring.
3. Quality of the steel as affected by the heating, rolling and slow cooling.
4. Quality (eccentricity, surface, structure) of the heavy walled tubes as affected by the piercing process.
5. Quality of the gun tubes as affected by upsetting, heat treating, straightening and stress relief.

These factors will now be discussed separately.

Chemistry — The Ordnance Dept. requires that war matériel must meet certain specified *physical* requirements, and it is the responsibility of the contractor to see that these are met. Therefore, the chemistry of the gun tubes was not specified. The original development work showed that good results could be expected from the A.I.S.I. 4300 steels, holding the carbon between 0.30 and 0.40%. Average chemistry ranges were 0.35 to 0.40% C, 0.75 to 1.00% Mn, 0.05% max. S, 0.04% max. P, 0.25 to 0.30% Si, 0.75 to 1.00% Cr, 1.75 to 2.00% Ni, 0.25 to 0.40% Mo.

This is a somewhat lower alloy steel than usual gun steels, but little difficulty was experienced in meeting the physical requirements, except when the nickel was dropped to between 1.10 and 1.25%.

Hardenability — To assure that the required physical properties could reasonably be expected to be met, it was the practice to test the hardenability of each heat of steel.

Jominy hardenability tests were taken from the first part and the last part of each heat as cast, or from the rolled or forged product representing the extreme bottom of ingots from the first and last portions of heats. These test pieces should show hardness values at the following distances from the quenched end:

When the quenched end Rockwells C-55 or higher, a minimum value of C-50 should be obtained at 24/16 in. from the quenched end, and C-48 min. 32/16 in. from the quenched end. Should the quenched end be under C-55 Rockwell, the hardness at 24/16 and 32/16 in. from the quenched end may be reduced a like number of points, but in no instance shall the quenched end hardness be under C-50 Rockwell.

If the predicted hardenability as determined from a cast sample, taken at the time the heat was poured, was below the standard specified, several billets from that heat were rolled and pierced and then piloted through the gun plant. If satisfactory physical results were obtained, the balance of the heat would then be processed from the blooms. Otherwise the heat would be diverted to other uses.

Fig. 2 — Piercing the Round Takes 15 Sec., Thus Providing a Rough Blank That Formerly Required 6 Hr. to Forge and Drill. Pierced round is immediately re-rolled for greater accuracy

Steel-Making Practice — One of the paramount factors in producing seamless gun tubes of high quality is the steel-making practice. It vitally affects the workability, especially in the piercing process, since ingots with bad centers not only result in piercing tears but may also cause large eccentricity. Steel-making practice also has a pronounced effect upon the physical properties, as a dirty steel will definitely have a low reduction of area in a transverse direction, and a high value of this property is one of the important characteristics sought in gun tube steels. Perhaps the greatest influence of steel-making practice is upon bore defects, which do not become apparent until most of the work has been performed on the tube and it is nearly completely machined. Whatever improvements are made in the steel-making process to better the cleanliness of the steel represent machine-hours, man-hours, and a great deal of money saved, because gun tubes rejected for bore defects represent a great waste all around. By far the greatest number of bore defects encountered in this program appeared to be caused by small non-metallic

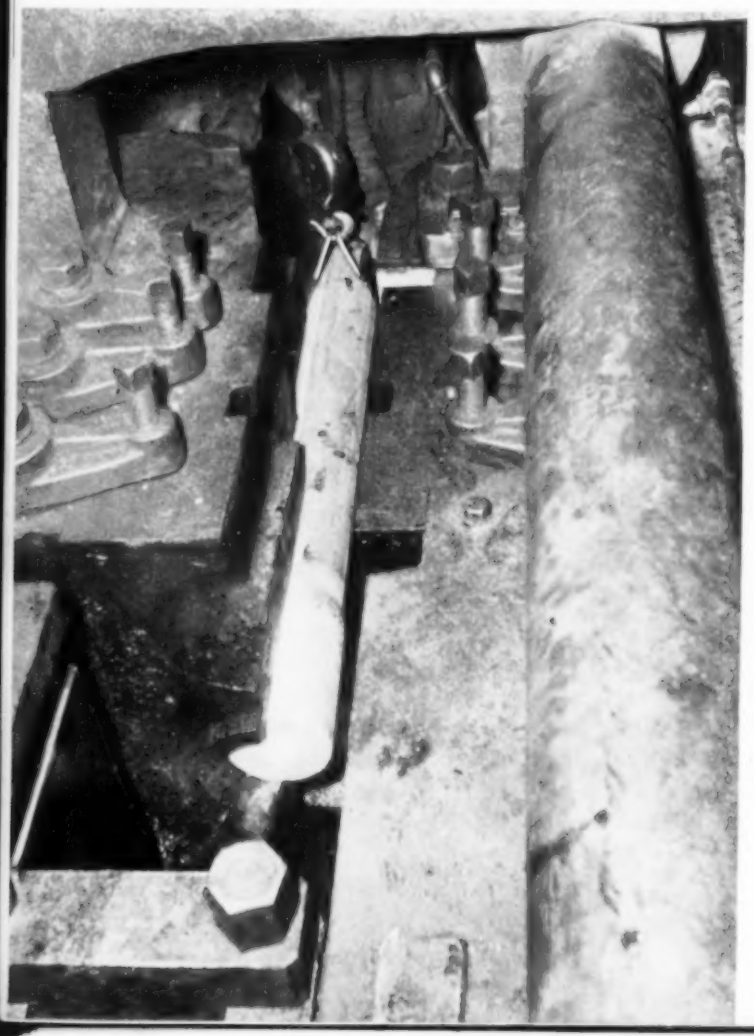
inclusions and stringers visible through the borescope in the lands and grooves of the rifling.

There were also other types of bore defects, such as those caused by bad machining, and some small quench cracks, but these constituted only a minority and the remedies were rather simple. Bore defects caused by non-metallic inclusions presented the greatest problem.

Good openhearth melting practice is essential to attain the required cleanliness. Fast heats generally do not make good gun steel, and the best heats were seldom under 12 hr. in the openhearth. It was found that the best deoxidation practice was to use a combination of calcium silicide and aluminum in the ladle, thrown in while the furnace was tapping. It is said that this type of deoxidation results in spherical deoxidation products instead of longitudinal inclusions.

Heats in which the carbon was blocked on the way down were found to be superior to those which had to be excessively "coaled" in the ladle. Heats should also be tapped hot enough to stay in the ladle long enough so most of the non-metallics can rise from the bath to the slag, and metal still be hot enough to teem properly.

Fig. 3 — Pierced Tubes Are Reheated on One End by High Frequency Electricity and Upset for Breech, Thus Saving Much Machining of Rough Forgings Down to Barrel Diameter. (Timken)



Good ladle practice is essential. The nozzle and stopper must be carefully set to avoid leaks and running stoppers. Ingots poured with a running stopper should be diverted to other less critical uses. The nozzle size should be such that, when teeming, the rate of rise in the molds is optimum to produce quality ingots.

All molds must be big-end-up, with good hot tops. As to cross section, 21-in. dodecagonal molds seemed to give excellent results, although good results were also obtained with molds as large as 26 by 26 in. Molds must be as clean as possible, and should be coated. It was found that cold molds seemed to yield poorer results than properly warmed molds. In several heats a condition was encountered in which macro-etch from billets (and also from the rough gun tubes) indicated that certain ingots had been poured with wet hot tops. These billets and tubes were rejected, and suspicion was cast on the entire metal in all of these heats, finally causing them to be declared unfit for gun tubes.

The National Defense Research Committee of the Office of Scientific Research and Development, War Metallurgy Division, sponsored a number of projects to study the effect of various factors upon gun tube quality. (Most of the work along this line was done at Carnegie Institute of Technology.)

One factor which good steel-makers have suspected for some time — and these studies have proven them to be right — is that the cleanliness of ingots is appreciably improved if back pouring is prohibited. (Back pouring is the practice of filling one mold to just above the bottom of the hot top, then filling the next mold to the same level, then returning to the previous mold to fill the hot top.) The common excuse for back pouring is that it seals the space between the mold and hot top so the steel will not drain out of the hot top. In practice, the time which elapses from the time the mold is filled until the hot top is filled is sufficient to allow non-metallics to rise from the depths to the surface, and when the hot top is filled, or back poured, the new stream of steel drives these non-metallics back down into the ingot, where some of them become trapped. For these reasons back poured ingots contain an excessive amount of non-metallic inclusions which eventually cause excessive rejections of gun tubes for bore defects.

After the molds have been filled, they should stand undisturbed until solidification is complete. Failure to observe this precaution usually results in weak centers in the ingots. This condition may cause bad piercing (and possibly bore defects as well).

Good steel mill practice requires that ingots be charged into the soaking pits as soon after complete solidification as possible. The reason for this is twofold: First, a maximum amount of residual heat in the ingots is conserved, requiring less fuel for heating; second, most alloy steels are sensitive to rapid temperature changes and rupture or flake internally if subjected to too rapid thermal shock. If ingots should remain in the molds until they are black, the soaking pits should be cooled sufficiently to receive them; after charging the temperature should gradually be raised to soaking temperature.

Croppage at the blooming mill shears should be sufficient to clean up any trace of pipe. The bottom discard usually is from 5% to as much as 10%, while the top crop is not less than 17%.

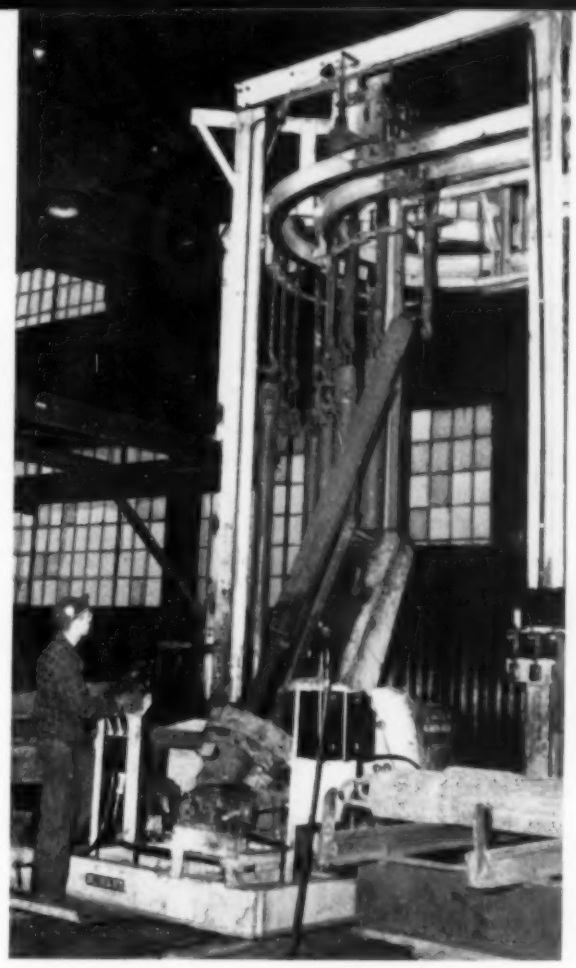


Fig. 4 — Production Line for 6000 75-Mm. Tubes a Month, Each Weighing 1400 Lb., Needs Special Equipment to Load and Unload Conveyers. Each tube has a bail welded to carry through the heat treatments

Rolling Mill Practice — Direct conversion of the bloom into round billets was found to yield superior results to double conversion.

In double conversion, the bloom is slowly cooled in burial pits for about six days. When cool enough to work on, the surface of the bloom is cleaned (conditioned) by chipping or scarfing. Blooms are then slowly reheated to rolling temperature and rolled into round billets. The billets then must be slowly cooled for six or seven days to prevent flaking.

Single conversion consists of rolling the blooms directly into billets, with no intermediate slow cooling and reheating. (The surface of the billets is conditioned before piercing, in either plan of operation.) Single conversion, in addition to materially shortening the time from ingot to billet, also lessens the likelihood of flaking, because one slow cooling and reheating cycle is eliminated.

Billets for the 75-mm. gun tube were 8 in. in diameter, weighing approximately 1400 lb. The yield was three billets per ingot.

Billets for the 40-mm. gun tubes were 6 in. in diameter, and weighed approximately 600 lb. The yield was usually seven billets per ingot.

Segregation — At this point one of the most interesting metallurgical phenomena encountered in the entire program should be mentioned. Metallurgists for years have believed that the soundest and cleanest steel in killed steel ingots cast in big-end-up molds with hot tops was at or below the middle of the ingot. The top third of the ingot was considered to be the dirtiest and highest in segregation, even with the best hot top practice.

Early in the seamless gun tube program, a great many tubes were being rejected after having been completely or nearly completely machined; it even began to appear as though the process might have to be abandoned.

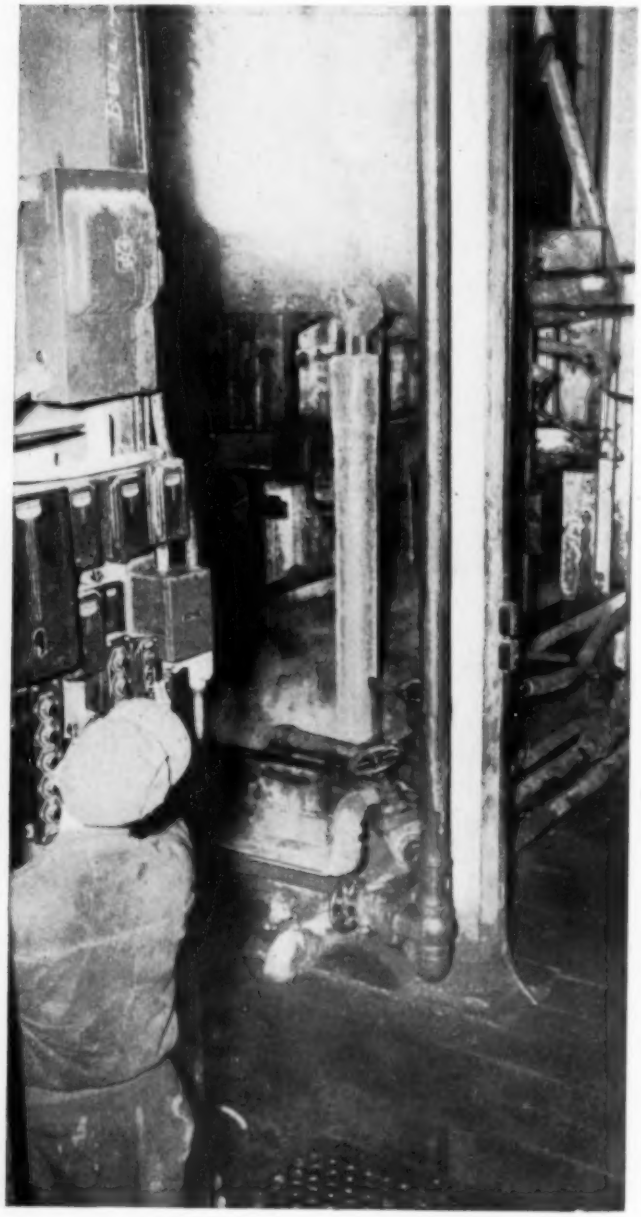
However, intensive studies were made to determine the reasons for these excessive rejections, and it was found that approximately 70% were in tubes processed from the *bottom third* of the ingots! This was true in heat after heat, on both the 75-mm. tubes, where only three tubes per ingot were obtained, and in the smaller 40-mm. tubes, where six or seven tubes per ingot were obtained.

Inspection records were then studied to find the related position of each tube to its original position in the ingot. Complete work sheets were compiled for each heat to show graphically the location of all tubes rejected at the gun plant. Requests were made to all machining sources that all reports should identify the nature of the rejection and its location in the gun tube with reference to the breech or muzzle. The results were tabulated and it was found that the zone of maximum non-metallic inclusions, which was the main cause for rejection, was definitely in the bottom third of the ingot. The graph, Fig. 6, on the next page, illustrates this.

As a further step all macro-etch disks from both ends of each gun tube were studied carefully and records made of their appearance. These records were correlated with inspection results, and standards of acceptance set up which allowed no rough tubes to be shipped for machining whose macro-etch disks did not meet the agreed-upon appearances. This substantially cut down the rejections during machining.

The steel producers had all become quite interested in the results, and cooperated in working out a correlation between the macro-etch of the gun tubes and the macro-etch of the round billets. The ultimate result was that by diverting the bottom third of ingots to other products, and using the top two-thirds for gun tubes, the rejections at the gun plant and at the machining sources decreased from more than 12% to less than 2%.

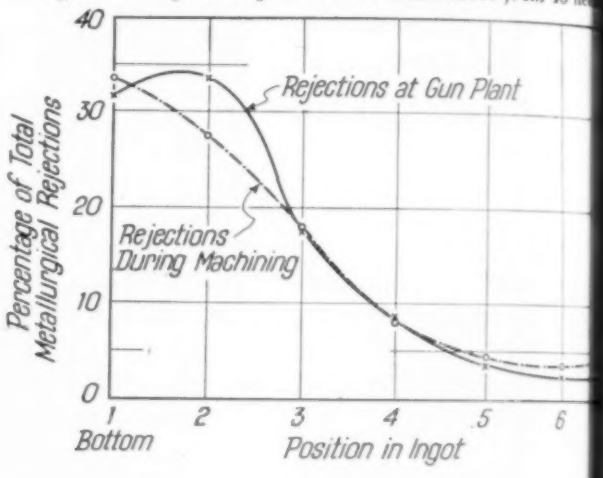
Fig. 5 — A 75-Mm. Fires Its First Shot — Out the Breech End! Being quenched in water, a stream is forced into the bore, and steam and water blow out the top. (Timken)



The National Defense Research Committee became engaged in this phase of the production program, and work has now been completed which has contributed greatly to the knowledge of what happens when an ingot solidifies.

Piercing — A seamless tube which is to be used for a gun tube is one in which the ratio I.D.-to-O.D. is much smaller than for the average seamless tube. The greatest problem encountered in the piercing mill when producing this thick walled tubing is eccentricity, or "run out".

Fig. 6 — Frequency Curves Showing Percentage of To Metallurgical Rejections Versus Position of Gun Tu Ingot. Analysis is of 12843 40-mm. tubes from 45 he



The piercing mandrel is of necessity small in diameter, and tends to whip or run off center, even when extra guides are in place. Uniform heating of the round billets is also necessary to control eccentricity.

Seamless tubes were accepted for processing into gun tubes under the following conditions:

1. The straightness is within the limits of the drawing.
2. The pierced hole is no larger than the drawing size.
3. No seams or other surface defects are present on O.D. or I.D.
4. The eccentricity or runout does not exceed 0.200 in.; this insures that the tube will clean up in machining.
5. No piercing tears are permitted.

Auxiliary Operations — A few tubes have been overheated or "burned" by the high frequency induction heaters used to heat the breech end prior to upsetting. This can be eliminated by proper control of the time cycle.

When a bail is welded to one end for hanging the gun tube on the conveyer line for transportation through the heat treating furnaces, occasionally cracks occur. Such rejections are avoided by reasonable care on the part of the welders. *(Continued on page 112)*

Effects of Pressure and Temperature on Iron Powder Compacts

By Charles O. Heath, Jr.
Instructor
and Joseph D. Stetkewicz
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Rutgers University
New Brunswick, N. J.

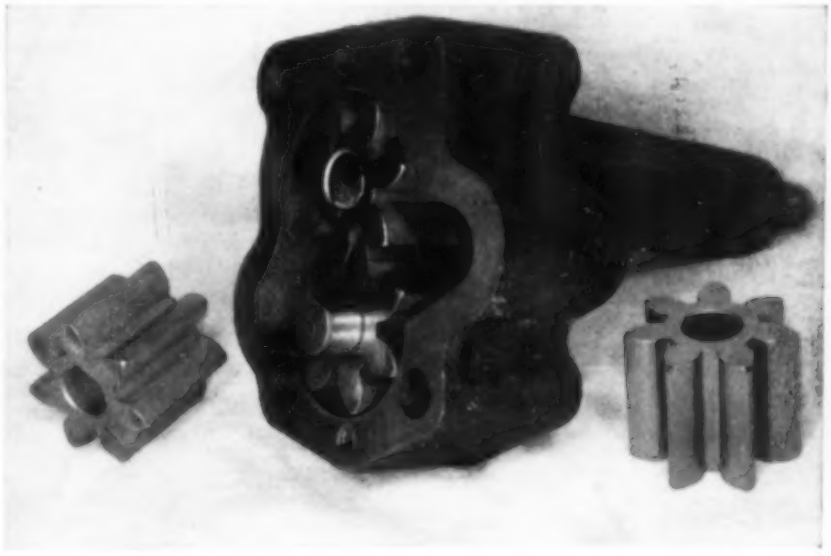
MANUFACTURE of small parts from metallic powders has now become a recognized method of fabrication where mass production can offset the high initial cost of equipment and dies. During the last few years, such dense metal compacts have offered real competition to the slower, skill-requiring machining and grinding methods of producing small parts of accurate, and often intricate, profile. An interesting example, where the sintered iron compact has replaced the cast and machined part, is the oil pump gear used in the automobile industry, shown in Fig. 1.

Briefly stated, the procedure consists of pressing a measured quantity of iron powder in a die under pressures up to 50 or 60 tons per sq.in. The green compact thus formed has a highly polished surface and considerable surface hardness, but lacks the strength necessary for use as a finished piece, so it is fired in a furnace with a neutral or reducing atmosphere at temperatures ranging from 800 to 1450° C. (1475 to 2650° F.). This temperature promotes sintering of the particles at contacting areas and results in a compact of greater strength, density, and toughness. Accompanying the increase in density there is necessarily a reduction in volume. Although tolerances of 0.001 in./in. can be maintained on finished pieces, some experimental work must usually be done before a proper die can be constructed, as correct allowance must be made for shrinkage during sintering.

Many factors affect shrinkage (and thus the change in density of compacts while sintering). The type of iron powder used is important, because different processes of manufacturing the powder result in differences as to particle shape, porosity, surface profile, and particle size. Even more important than these is the *distribution* of particle size; best results are obtained where the size of the particles ranges from a few microns to —100 mesh. Any change in the proportion of fine, medium and coarse powders will affect the final dimensions of the compact, an increase in the proportion of coarse resulting in greater density of compact or less shrinkage after sintering, this effect being greater axially than radially to the direction of compression.

Besides variation in the powders themselves, the three most important variables affecting density are the pressure used in pressing the compact, the temperature of sintering, and the

Fig. 1 — Oil Pump for Automobile; Cover of Cast Iron Case Has Been Removed to Show Assembly; Spare Gears or Impellers Shown Outside Are Made of Iron Powder. (Lenel)



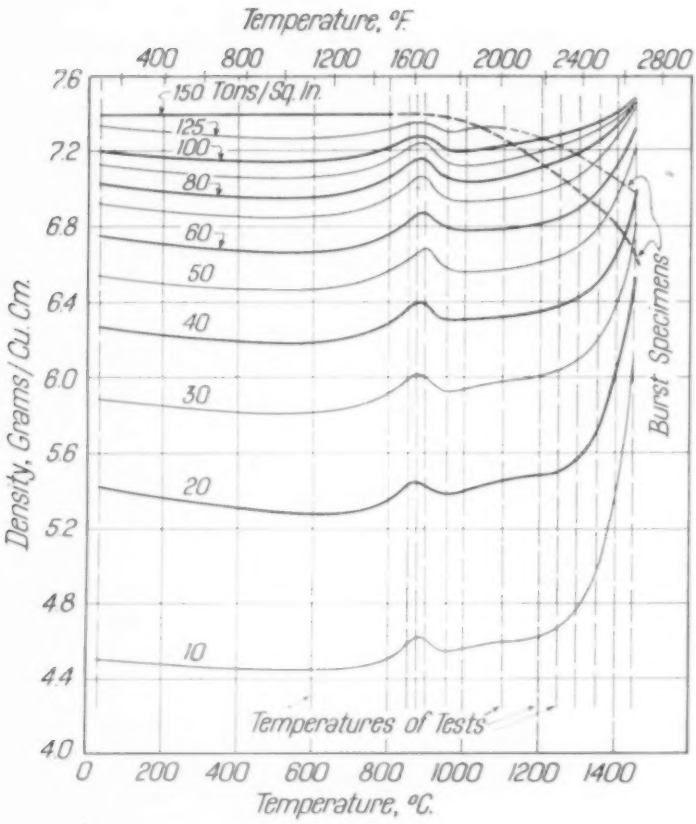


Fig. 2 — Relation of Sintering Temperature to Density of Iron Powder Cylinders, Compacted at Various Pressures. All samples sintered in hydrogen for 1 hr.

length of time the compact is held at sintering temperature. The final density and dimensions will depend upon the particular combination of these three variables. Consistent production to close dimension therefore requires very accurate control of temperature, of time in the sintering furnace, and of furnace atmosphere, as well as the production of identical compacts in the presses.

Of the variables just mentioned, pressure is the most important when moderate sintering temperatures and times are used. F. C. Kelly has shown, in an article on "Powder Metallurgy" in *Canadian Metals and Metallurgical Industries* for December 1941, that all compacts approach or reach the theoretical density of pure iron (7.86 g./cu.cm.), if held at a temperature of 1450° C. (2650° F.) for a long enough time. German investigators had previously found that loosely packed iron powder with an apparent density of 3.0 would attain a density of over 7.0 when sintered at 1400° C. (2550° F.) for 24 hr.

Of course, a high final density is not the only criterion when close tolerances must be maintained. The large shrinkage on sintering compacts formed with low pressure results in uneven dimensional changes and frequent warping. Then, too, production furnaces cannot be operated profitably at temperatures above 1100° C. (2000° F.), and sintering times of 32 to 64 hr. cannot be considered in mass production. Thus, higher compacting pressures lead to a closer control of final dimensions and higher strength, when sintering temperatures and times must be kept at a minimum.

In our experiments on the sintering cycle we used a commercial iron powder made by reducing iron oxide powder in hydrogen, supplied by the Metals Refining Co. of Hammond, Ind. Its chemical analysis and screen analysis are:

Chemical Analysis

Iron	97.0% min.
Total carbon	0.5% max.
Insoluble	0.5% max.
Phosphorus	0.03% max.
Sulphur	0.02% max.
Hydrogen loss	1.50% max.

Screen Analysis

On 40 mesh	0%
On 100 mesh	0.3%
Coarse: On 200 mesh	43.3%
Medium: On 325 mesh	30.6%
Fine: Through 325 mesh	25%

Because of its simplicity of shape and the ease of obtaining dimensional measurements, a cylindrical compact was used. Although it is generally known that the axial dimensional change on sintering is greater than the radial change, the latter was used in determining shrinkage since it can be measured with greater accuracy. The compacts formed were approximately ½ in. diameter and from ½ to ¾ in. long. The same weight of powder was used for each sample and the compacting pressures varied from 10 to 150 tons per sq.in. Pressing was done on a 200,000-lb. testing machine, the load being applied at such a rate that a pressure of 50 tons per sq.in. was reached in about 15 sec.

The green compacts thus formed were sintered for an hour at temperatures ranging from 600 up to 1450° C. (1100 to 2650° F.). This was done with a hydrogen atmosphere in a single tube, Sentry electric combustion furnace with Globar heating elements.

Twelve samples, each pressed at a different pressure, were stacked in three rows of four each on a strip of asbestos ribbon. Each sample was separated from the others by asbestos paper to prevent their sticking together. The specimens were carefully positioned in the tube and the tube placed into the furnace so that all the specimens lay within the constant temperature section of the furnace, 3 in. long.

A rubber stopper, protected on the inside by

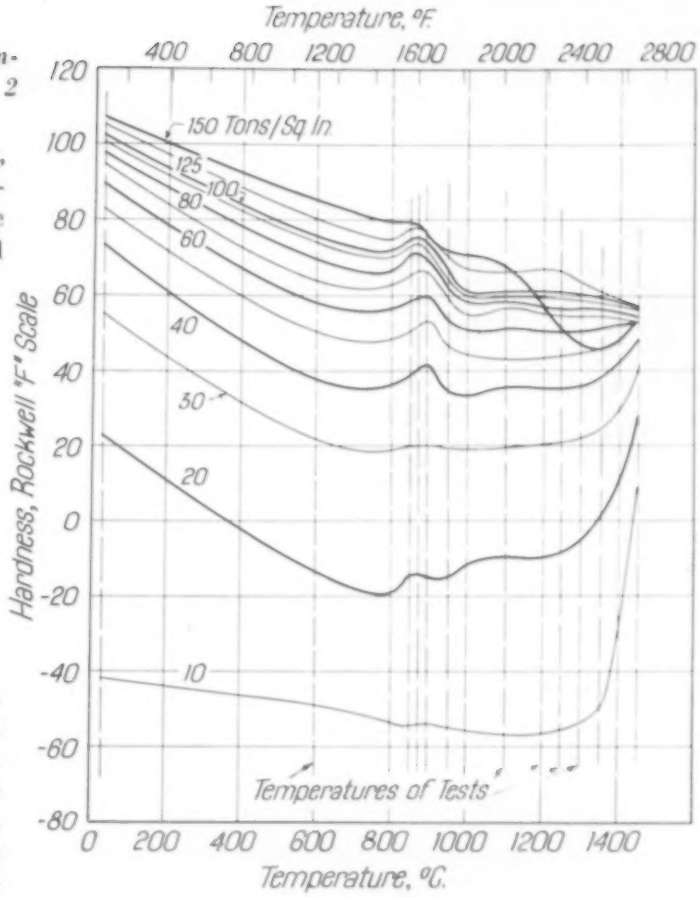


Fig. 3 — Rockwell F-Scale Hardness Vs. Temperature of Sintering for the Samples of Fig. 2

asbestos and containing a ¼-in. quartz tube, was placed in the open end of the tube. Hydrogen was fed from a tank through a pressure regulator into the combustion tube and burned as it emerged from the small quartz tube at the other end. A 2-in. flame was maintained which consumed hydrogen at the rate of about 20 cu.ft./hr.

Figure 2 shows the effect of temperature on density. The first decrease in density from that of the green compact is due to the "hydrogen loss" — that is, the sample actually loses weight in the hot hydrogen atmosphere by reduction of oxides in the powder. At approximately 875° C. (1600° F.) there is a peak in the density-temperature curve, the effect spreading over the $\alpha \rightarrow \gamma$ transformation range. Similar results were reported by Libsch, Volterra and Wulff in Chapter 35 of the book "Powder Metallurgy", and are attributed to a slight expansion of entrapped gases during the atomic rearrangement accompanying the iron's transformation. Our investigations show that this characteristic change in density occurs for all compacting pressures. As the sintering temperature is increased, the density again increases slowly. It is not until 1100° to 1200° C. (2000 to 2200° F.) is reached that the density again equals the value attained at 875° C.

Above 1200° C. the density increases rapidly, with even greater changes above 1350° C. (2450° F.). The greater increase in density is found where low compacting pressures were used. However, the greater the compacting pressure the higher the actual final density for any one sintering temperature up to 1000° C. (1825° F.). Very high compacting pressures, combined with relatively high sintering temperatures, burst the compact, as evidenced by a decided bulge in its ends. In severe cases the sides of the compact were cracked horizontally at right angles to the axis throughout the entire length. Although lamination is inherent in the green compact due to the relative motion of powder in the center and at the edge (that which tends to cold weld to the side of the die), the actual rupture is probably due to the violent escape of entrapped gases. Its effect on density can be seen in Fig. 2. The sample at 100 tons per sq.in. showed no bulging until sintered at 1450° C. (2650° F.). The samples pressed at 125 tons per sq.in. began to show this condition at 1200° C. (2200° F.), while the 150 tons per sq.in. samples were affected at 1100° C. (2000° F.).

The hardness curves, Fig. 3, are related to those for density. The high initial hardness of the green compacts of course results from the work-hardening during pressing. The relative hardness is always similar to the relative density for compacts given the same sintering treatment.

It should be emphasized that hardness is not a reliable means of comparing compacts which have variables other than those existing in these experiments. Iron compacts of different composition, especially those containing combined carbon, may have the same density with widely varying values of hardness.

Where dimensional changes are concerned, Fig. 4 shows that the reduction in diameter, or shrinkage upon sintering, follows very closely the change in density. Here again the values obtained at 850 to 900° C. (1560 to 1650° F.) are nearly the same as those at 1200° C. (2200° F.), and the shrinkage is generally less at the higher pressures.

One interesting characteristic is apparent from these curves. Where minimum dimensional changes must be maintained, pressures of 50 to 60 tons per sq.in. give better results on this iron powder than pressures from 70 to 100. Figure 4 also shows that if shrinkage is to be kept at a minimum, high sintering temperatures must be avoided.

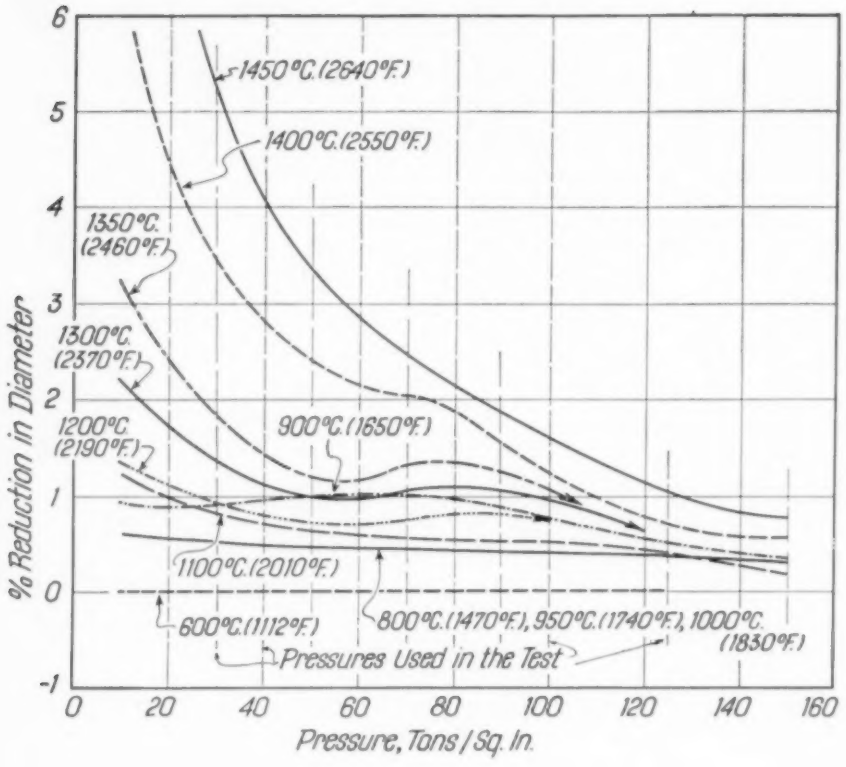


Fig. 4 — Reduction in Diameter During Sintering as Related to Compacting Pressures and Temperatures of Sintering. All samples sintered in hydrogen for 1 hr.

Summary

It is clear that pressure is the more important variable at temperatures below 1400° C. (2550° F.). The variations due to changes in pressure are of greater magnitude and are more consistent than those due to temperature.

It is apparent that where density, hardness, and strength are desired, and moderate temperatures must be used, there is no advantage in sintering above 900° C. (1650° F.). In fact, there is a definite reduction in these properties at higher temperatures, and this is true for all pressures tested. If higher density and strength are desired, the compacts must either be sintered at temperatures above 1100° C. (2000° F.) — which is too high for the common electric furnaces heated with nickel-chromium resistors — or some different method of processing must be used, such as the hot-press or a re-press after sintering.

When dimensional change or shrinkage is of major importance, however, there is a decided advantage in sintering at 950 to 1000° C. (1750 to 1825° F.). Variations in pressure would then have little or no effect on the cross-sectional dimensional changes. In addition, small temperature variations either higher or lower would influence shrinkage in the same direction, thus leading to greater control of final dimensions and the maintenance of closer tolerances.

When high hardness is desired, the lower sintering temperatures give the better values, especially for pressures above 40 tons per sq.in.

In applying the results of this and similar investigations to the actual production of compressed and sintered parts, it appears that two general procedures should be followed:

The first would be used for parts where final dimensions and the maintenance of close tolerances are of primary importance. The green compacts should be sintered at 950 to 1000° C. (1750 to 1825° F.). The required strength of the part would determine the compacting pressure required. However, if pressures greater than 50 tons per sq.in. were needed for the required strength, excessive wear of the dies would result and other methods of fabrication should be considered. The length of time of sintering would require careful investigation in order to determine the proper heating cycle. This time would possibly be from 10 to 60 min. In setting up a production schedule, it would seem best to maintain the heating cycle constant and to vary the compacting pressure as necessary to take care of other variations such as irregularities in the powder supply, wear of the dies, and so on.

A different procedure should be used where highest density and strength are essential and tolerances are of secondary importance. Compacting pressures should then be as high as is economically possible, considering the wear of the dies. If an electric furnace with the common nickel-chromium heating element is to be used, the compacts should be sintered at 850 to 900° C. (1560 to 1650° F.) for as long as possible. Here again the optimum time must be determined. Better results could be obtained with a special furnace capable of heating above 1200° C. (2200° F.). With a continuous furnace the compacts could be fed into a preheating zone kept at, say, 850° C. (1550° F.); from this they would go to the high temperature zone at, say, 1200 or 1250° C. This would have to be followed by a cooling zone in which the compacts were cooled to 150° C. before they could be removed.

A simple test specimen such as used in this work is valuable for production control, because variations in it due to changes in operating conditions or raw materials may be expected to produce similar changes in the more intricate parts being actually manufactured.

Critical Points

By the Editor

ALMOST like the hectic days after Pearl Harbor to be in Hughes' Aircraft Strut Plant near Houston, Texas, now converting from a factory for aircraft landing gear to a huge forge and machine shop to make a million shells a month, 155-mm. high explosive and 105-mm. chemical. Finishing departments for 155's, forged elsewhere, are in full operation; others are betwixt and between. The shells are so heavy that they travel endwise, everywhere, in trough-like conveyers, waist high. In this particular plant a battery of tools — enough for a single operation — is completely surrounded by a conveyer and the shells go 'round and 'round until slid off into one of the machines. Lathe tools are used in such quantity they are delivered from the tool room in trucks! Roughing tools are especially husky, for 30 lb. of steel is hogged off a shell in 2½ min. Each special lathe has six cutters for side profile and two for end cut-offs; each tool is a 2x2x9-in. carbon steel bar with a carbide nib brazed on. Brazing is very easily done by sliding the assembly under a simple loop of copper tubing carrying cooling water inside and high frequency electrical current outside.....Nosing the rough finished shell is a critical operation. The correct distance is heated along the sides from the open end by inserting the shell into a port-like opening of a ring forming the moving outer wall of a circular furnace; the correct temperature is had by pyrometric control and timing for the complete circuit; the nosing die is warmed at the start by a gas burner, then kept from overheating by water cooled passages. The nature of the die lubricant is critical in obtaining the proper nosing action..... Shell hardening is done in open flame furnaces; eight parallel lines of shells are carried through, end to end, on traveling conveyers. The hot shells strike the oil nose-first and drop into a submerged pot that sprays their sides vigorously. A jet also strikes the open end and drives oil up inside, but a spray pipe entering inside of the 105-mm. chemical shell is necessary to get the required fast quench. A draw, in a furnace with recirculating atmosphere (ordinary air, not prepared) delivers shells with a very light scale, ready for shot blasting inside and finish machining outside. Hardness averages 255 Brinell. Some idea of the amount of equipment may be had by the fact that six furnace lines (heat, quench, draw) are necessary to handle the 105's alone.....Observed that in shell production it appears to take almost as much labor to inspect the piece in process and at the end, including final re-check by Government inspectors, as it does to make the thing. Consequently a "Sheffield Multicheck" gage that measures diameters at eight positions simultaneously, and in a fraction of a second, is a time saver. There is, of course, nothing new about the idea of automatic gaging; this equipment, indeed, was notable more for its compactness — furthermore, a girl can roll, nonchalantly, an 85-lb. chunk of steel into it and out again without affecting its adjustment. The shell stops in a cradle, eight pairs of fingers quickly close into contact, eight signal lights flash; if all flash white, a master light signals and the shell is on its way.

Forging and treating large caliber shells

Eight-position automatic gage

IN THE INTERVAL between world wars, men at Watertown Arsenal perfected the method (vigorously sponsored by Gen. T. C. DICKSON, then commandant) of *casting* gun barrels, rather than using heavy forge equipment, as in the conventional methods. At the outbreak of this war it became apparent that there was not enough forging and pressing equipment in the country to make the necessary artillery — along with all the other ordnance and munitions for Army, Navy and Air Forces — so a plant of about Watertown's capacity was hurriedly built on the flat lands near Houston, Texas — one of those construction marvels wherein production started less than a year after the cows were shooed off and foundations built.....The principal difference in manufacturing practice over that described by General DICKSON in his paper in 1930 *Transac-*

tions of the American Society for Steel Treating is that the tubes are not strengthened by autofrettage (there being no chance to get the necessary hydraulic equipment in those early hectic days). The necessary physical properties are given by the following heat treatments: The casting is slowly cooled in ashes (2 days), then homogenized at 2200° F. for 16 hr., air cooled, and after rough machining, is quenched and tempered (water cooled after each heating). Exact heat treatment schedules vary with the size of tube and chemical analysis of the steel; very good transverse properties can be achieved and the cast barrels are rated equal to forged barrels by Army artillerists.....Test disks cut from both breech and muzzle ends, after smoothing and pickling, show well defined and large primary crystals, ranged radially. These are less prominent after the homogenizing treatment, but are easily found again after quenching and tempering. Evidently the undiffused constituents that are responsible for this macrostructure have no harmful effect on the properties of a gun tube in use. More serious are circular bands or abrupt changes in structure, band to band, as developed by the deep etch test. Exact causes of these aberrations in the normal disposition of the liquid steel are as yet unknown; if they are undiffused by the long homogenizing treatment and happen to be located near the grips in a test specimen they may throw the fracture outside the gage points—a cause for rejection, as it indicates non-uniform steel.....The casting shop has a row of ten casting machines, each with its individual Ajax induction furnace for melting the steel. Castings for the largest tube made at the Dickson Gun Plant—the long 90-mm. anti-aircraft or Pershing tank gun—are 18 ft. long and weigh about 5000 lb. The tapered casting is made in an even more pronouncedly conical mold, since extra cold metal is required to chill the extra steel at the breech end. These conical molds, of ordinary mold iron and of life about equal to a good ingot mold, are fitted into a steel casing that, in turn, is rotated about its axis by roller nests in massive housings at either end. Open ends of the mold are closed by refractory lined plates, except for ¾-in. central hole. Molten steel enters from a preheated pouring basin, out of the bottom of which leads a ⅝-in. round sprue that butts against the central hole in the plate closing the breech end. Rotation, at about 1200 r.p.m., is a balance between the needs of the metal at the bigger breech end, at the smaller muzzle end, and at the axis of the casting—which by the way is almost entirely filled, there being a central hole remaining no bigger than your thumb. This need for striking an average for such varying casting necessities is the cause of many compromises in practice throughout the entire manufacture of the gun. For the larger guns it takes about 5 min. to pour the hot metal and about 25 min. for it to solidify. The hot solid casting is then forced out of the mold by a ram set in line with its axis at the rear of the machine. If about 15 min. is allowed for unloading the mold, minor clean up, fixing end plates and pouring box, the furnace serving that machine must be able to melt its charge in less than an hour.....Melting stock is 4-ft. lengths of scrapped gun castings and 2-in. square bars of nice clean 1020 steel—no "scrap" in the ordinary sense. The induction furnace is a pure melter, and for gun making requires a compact charge of excellent steel. Some slag scours from the furnace lining. After the alloy additions, the melt is killed with a little ferrosilicon. Temperature and fluidity must be high—fluidity especially, else the ⅝-in. nozzle from the casting box will freeze up. The induction furnaces are very handy in many ways; they are quick melters, and the heat can be held, cooled or brought back to heat if there is any delay at the casting machine; likewise the furnace may be picked up bodily and acts as a pouring ladle. Disadvantages are that quality melting stock is required, and that some slag gets into the pouring box because the furnace is really a lip-pouring ladle.

Centrifugal casting of gun tubes

Induction furnace a combination melter and ladle

TO HALETHORP, south of Baltimore, where Uncle Sam has built a plant for casting aluminum and magnesium billets and extruding them into tubes and other useful shapes. It is operated by Revere Copper & Brass, which has also converted part of the capacity of its old Baltimore mills from sheet copper and brass tubing (largely used by the now dormant building industry) into the wartime manufacture of magnesium sheet and aluminum tubing. (Mayhap the experience America is getting in magnesium may well be a godsend in another emergency, when magnesium could act as a strategic alternate for aluminum, since magnesium chlorides and carbonates are present in infinite quantity whereas good bauxite ore for aluminum is comparatively scarce. Indeed, magnesium at present is almost unique in being available for civilian consumption without restrictions other than imposed by the man-

Casting of magnesium billets

power shortage.).....Casting of magnesium billets was especially interesting to see. The metal is melted and alloyed in a row of stationary pots, then pumped over into holding pots (also in fixed settings) to separate it from the flux and adjust its temperature. Pumps are rotary, air driven; transfer pipes must be hot end to end, else the metal will freeze at the very start. From holding pots it is next pumped in a small stream into casting units quite similar to those used for casting slabs of aluminum alloy — described in "Critical Points" of January, 1944 — except that the pouring box is covered and the molten magnesium is protected by an SO_2 atmosphere; each pouring box serves as a header to feed a group of collar-like molds, so several long billets are cast simultaneously on a slowly descending platform. Proper adjustment of metal's temperature, casting rate, temperature and quantity of cooling water is necessary, not only to control segregation in the alloy but also to prevent disastrous splits. At best the surface is rough; the billets are deeply scalped on lathes or milling machines before extruding.....A battery of extrusion presses of various capacities are so well protected by safety devices, and their movements reproduced in dials and pointers showing pressures and travel, that almost all the old-time rule-of-thumb has been removed from the operation, once the correct schedule for either aluminum or magnesium has been set up. Aluminum extruded tubing, ready for draw benches, is notable for its excellent internal surface. In the Halethorp practice, short billets with a bored axial hole are extruded over a tapered mandrel, a beautifully polished piece of toolsteel, 12 to 14 in. long, and about 0.10 in. smaller at one end than at the other. As the ram advances the mandrel also moves slowly forward, presenting constantly a new surface at the neck between die and mandrel. Any particles of metal picked up by the mandrel are therefore moved forward where they will not scratch the surface being formed. Of course, the extruded tube is slightly thicker in wall at one end than at the other, but this is ironed out in the first draw in the series necessary to bring it down to specified dimensions and physicals.

Tubes extruded over tapered mandrel

DISCOVERED at Trinler, Inc., in Chattanooga, more activity than ever I did see concentrated in one small building no larger than a service garage, all concerned with machining track treads (grousers) for the Army's high speed tanks and gun carriages, two every minute. Beehive is the name for it! Manganese-molybdenum steel castings, 0.40% carbon, are delivered from various foundries, previously annealed to about 230 Brinell for machinability. Rough casting dimensions are close enough so parallel surfaces for linkage are broached, first a roughing, then a finishing pass. (Finished tolerances are held to 0.002 in.) Connecting-pin holes are also drilled slightly undersize and broached to accurate diameter.....The item of metallurgical interest here is the flame hardening equipment. Two 1x4-in. wearing pads on each piece must be hardened ¼ in. deep to Brinell 477 min. Hardening is done after ends of the linkage lugs are broached to dimension, so the grousers nest together naturally on a short piece of track placed across a long table that oscillates sidewise about 3½ in. Held stationary above the front edge of this table are two standard Airco 1-in. oxy-acetylene heating heads, one for each lug on the grouser underneath. The flame is steady, the lug is moved back and forth under it; the heat is so adjusted that the proper area and depth of metal is heated to above the critical temperature in exactly one minute. The operator watches the second-hand on a nearby clock, and as it crosses 60 he merely pushes the next lug into place along the track, the heated grouser falling off the end into a water quench. Torches are water cooled, and their overflow is enough to prevent the quenching water from getting too warm. L. J. LEACH, superintendent, says that this equipment is much more simple than his earlier machine for hardening grouser treads progressively; in this the flame inched along the tread, and was followed immediately by a quenching spray — a "Rube Goldberg" mechanism turned the flame and quench water on and off at proper times as the castings were carried along on a conveyer. Experience with the older machine also indicated that the hardened zone was considerably deeper at the trailing end of the lug in any continuous passage of the flame. This might have been avoided by a flame control that would deliver the most heat at the beginning, tapering back toward the end and shut-off, but all this complication is avoided in the new device by heating the whole area of the pad before quenching. Furthermore, the flames now burn continuously and the blowpipe tips — according to LEACH — have far longer life than ones with on-and-off flames. Treads are hardened before near-by holes are drilled and broached; if hardened after finish machining the hole is likely to go undersize, not so much by warpage of the metal as from a film of charred cutting oil.

Flame hardening grouser lugs

By J. Paul Deringer
Chief Metallurgist
Jack & Heintz, Inc.
Bedford, Ohio

Bearing Races Improved by Isothermal Treatment

UNABLE to obtain sufficient ball bearings for its production of automatic pilots, generators, starters and other aircraft accessories (Fig. 1), Jack & Heintz, Inc. was authorized by the Army Air Forces and War Production Board in 1944 to establish a new plant exclusively devoted to ball bearing manufacture. Manufacture of such parts of highest precision has been largely confined to a specialized industry employing highly skilled craftsmen and metallurgists; consequently it is of interest to see how this company approached and solved that important phase of production resting in the heat treating department. Moreover, outstanding results have been obtained in both quality and quantity of work, associated with generous economic advantages as outlined in an accompanying cost analysis (Table I, page 85). Altogether the performance reflects yet another accomplishment of the isothermal heat treatment.

While the new factory plans were being drawn and current industrial practices for hardening S.A.E. 52100 steel bearings were being investigated, urgent need compelled immediate production and bearings were hardened in our existing heat treating equipment. Bearings ranged through seven sizes from the smallest (with an inner race of 0.375 in. i.d., 0.508 in. o.d. and thickness 0.280 in.) to the largest outer race of 2.665 in. i.d., 2.835 in. o.d. and 0.470 in. thick. This originally-used process, not at variance with methods currently employed by most old-line bearing manufacturers, consisted of a conventional quench and temper. Characteristic difficulties with distortion required piece-by-piece handling and die-press quenching of the larger sized bearing races, yet resulted in an average 0.003-in. out-of-round on 2.835-in. rings, as well as other excessive dimensional changes in smaller rings. (See Table II, page 86.) Such deficiencies, plus others of at least equal if not greater importance — such as degree and variance of hardness — became major objectives to be overcome with new methods and equipment.

One of the most important factors to be considered in new hardening equipment is its ability to prevent any decarburization. This 52100 steel, with 1.00% carbon and 1.5% chromium, readily decarburizes; actual trials with modern atmosphere furnaces failed to produce test specimens which would meet specifications for surface carbon. Distortion had to be held to an absolute minimum, and a scale-free surface was a further insistent factor, since our plans required a prefinish on bearings to closer tolerances than currently practiced by a majority of bearing producers. A further consideration was the limitation of available floor space for heat treating facilities.

Specimen Treatments

Thorough inquiries about methods and equipment were made, and sample pieces were hardened by various equipment manufacturers. Reported successes in salt bath austempering of S.A.E. 4140 fuses, W.D. 1075 pistol parts, and ordnance material made of other steels, directed our attention to the isothermal heat treating process. Fundamentally, as is doubtless well known, isothermal treatment involves the heating of steel to cause its constituents to go into uniform solid solution (austenizing), then quenching at a cooling rate selected from "TTT" or "S" curves for

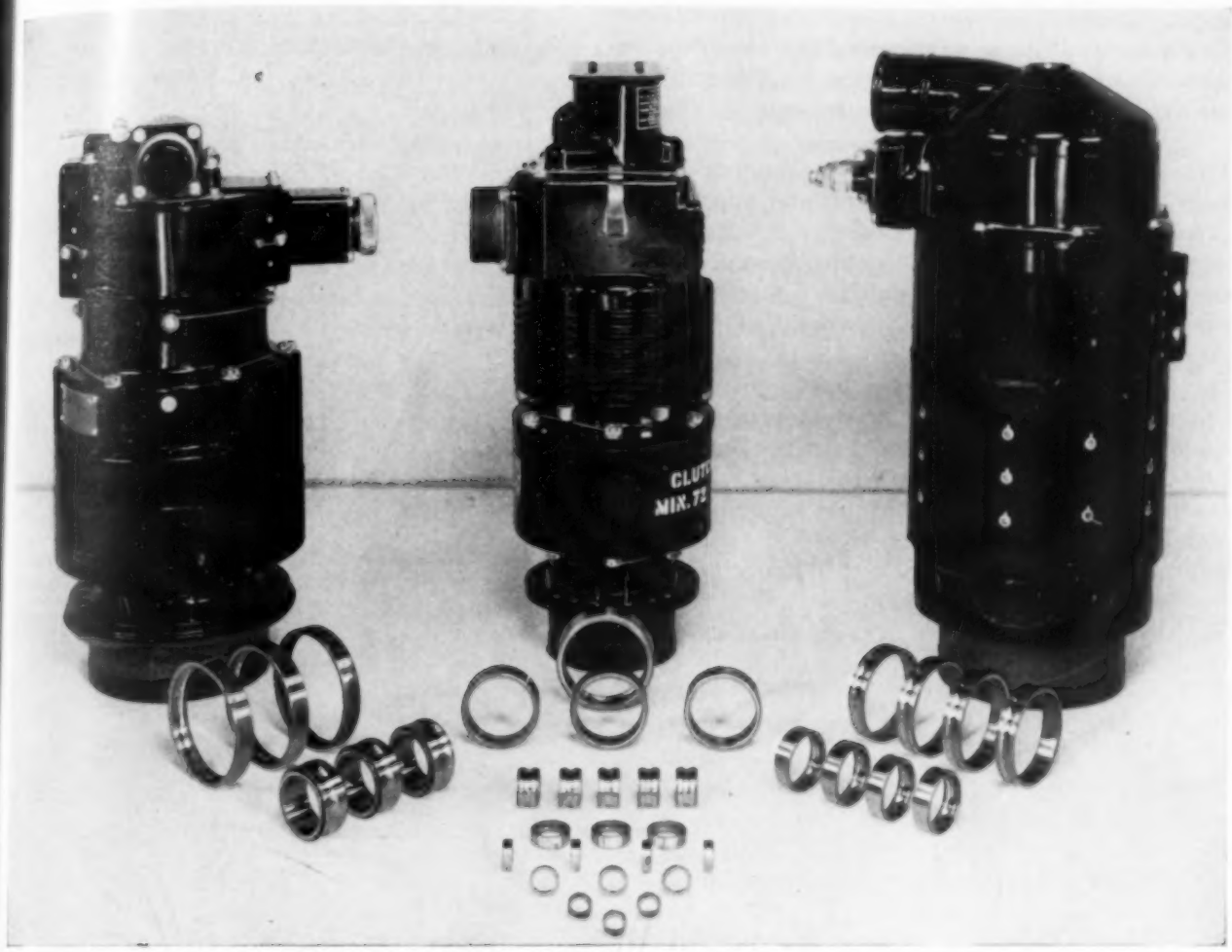


Fig. 1—Generators, Starters and Automatic Pilots, and the Various Sizes of Bearing Races Used in the Equipment. Largest rings are 2.835 in. o.d.

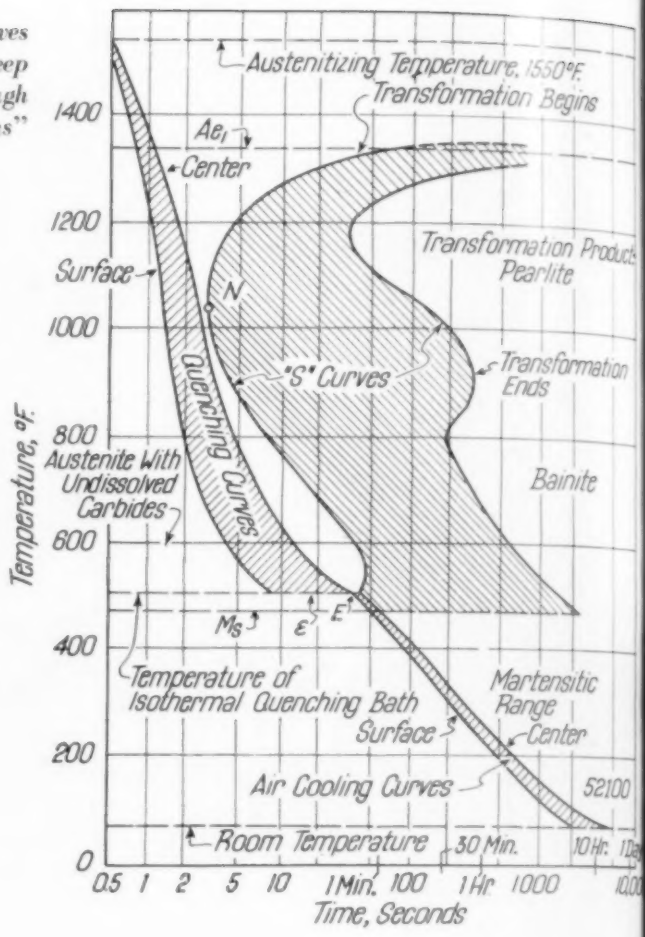
the particular grade of steel into a liquid bath at a correct elevated temperature until transformation of the austenite is substantially complete.* This heat treatment is known as "austempering", although the complete process is often referred to as a "three-step process", since the structure and physical properties, primarily controlled by the temperature and time in the isothermal quench, may be further modified by a subsequent drawing operation.

In consultations with metallurgists of Ajax Electric Co., and upon their treatment of specimens and investigations of proper time-temperature cycles, we concluded that some variety of the isothermal process could meet all the requirements stated above. In the conventional hardening methods, the quench into oil produced distortion and left residual stresses which were not eliminated by the stress relief operation that followed. A high temperature salt bath provides about the same cooling rate as warm oil, and is known to reduce distortion and to increase the ductility of the steel so treated.

A study of the time-temperature-transformation curve for an S.A.E. 52100-B steel indicated that a "martempering" treatment in molten salt, rather than an austempering, would produce the required physical properties. Martempering is a method of interrupted quenching for obtaining a structure of martensite with a minimum of residual hardening strains. The process (illustrated in Fig. 2 which shows the cooling curve in relation to a TTT curve for S.A.E. 52100 steel) essentially consists of quenching the work from an austenizing bath to a uniform temperature just *above* where martensite begins to form, holding it there long enough for the temperature to equalize, center to surface, and then, prior to the beginning of transformation, removing the part from the quench bath and cooling it to room temperature. The object of the first quench is to equalize the temperature within the piece; for

*A complete survey of this field of heat treatment is contained in the article by A. P. Seasholtz, in *Metal Progress* for October 1944, entitled "'Interrupted' Quenching in Salt Baths".

Fig. 2 — In the Martempering Process the Cooling Curves for Surface and Center of Quenched Piece Must Be Steep Enough and the Equalization Period at E Short Enough to Miss the Curve Marked "Transformation Begins"



this, the bath must be isothermal — that is, held at a chosen temperature without appreciable change up or down. Likewise it must be capable of a high rate of cooling in order to quench the steel fast enough to get past the "nose" of the curve near *N*, without allowing any pearlite to form.

The time that the piece being quenched remains in this isothermal martempering bath must not be long enough to pass beyond the line marked "Transformation Begins". The cooling power of the bath should be ample to stabilize the temperature between the inside and the outside of the heavy sections being quenched before any transformation begins. The piece, with a uniform temperature throughout, is then removed from this bath and allowed to cool in still air. Now, as the piece cools, martensite forms but, as the cooling rate in air is slow, there is only a slight difference in temperature between the outside and inside of the piece. Thus the transformation takes place at a slow rate uniformly through the cross-section, and minimum internal strains, if any, remain.

Test bearings were austenized at 1580° F. in a liquid salt bath, quenched in hot salt at 500° F., and air cooled, whereupon a hardness of C-65 to 66 was uniformly obtained. The quenched structure had the fine fracture grain desired in bearing steel. Stress relief at 350° F., also in a salt bath, modified the hardness to the desired C-63 to 64. Races were practically free from distortion without resorting to die press quenching. Freedom from residual stresses in specimen races thus treated was ascertained with a test frequently used by bearing manufacturers, consisting of cutting through the ring section with a slotting-cutter. If residual stresses are present.

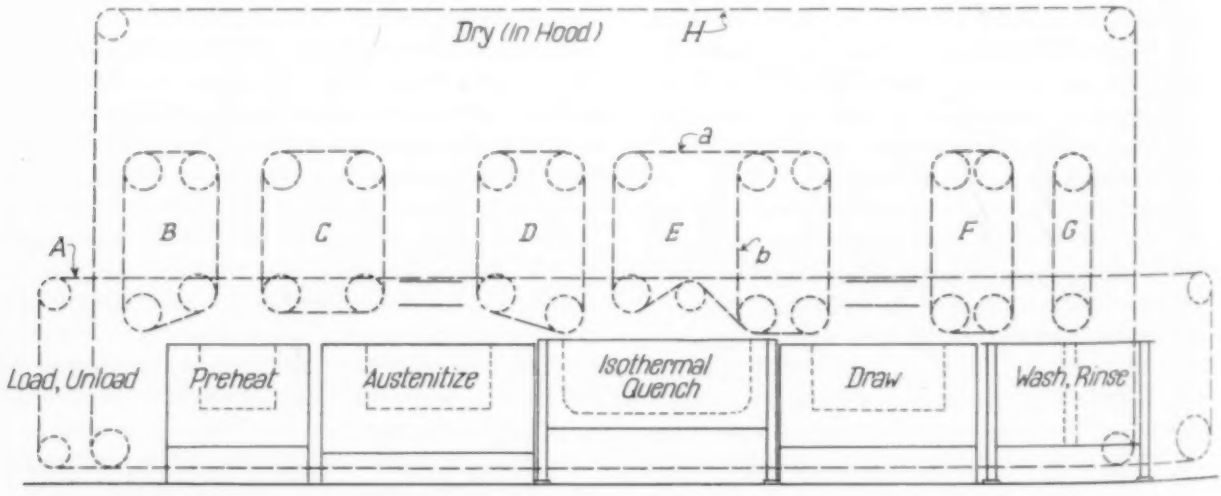


Fig. 3 — Sketch of the Furnace Line-Up, Showing Flow Direction and Conveying Sequence. Transfer mechanism E may be adjusted for either one of two routing lengths, a or b, to alter equipment from martempering to austempering process cycles

the cut ring will "spring" apart in excess of the known thickness of the tool's cutting edge. The difference in these dimensions is readily measured and accepted as an index of residual stress.

Work conducted in the experimental department of Ajax Electric Co. led to specimen treatment of races varying in diameters from 3.4 to 9 in. and showed upon cutting that all except one 8½-in. bearing remained unchanged in the dimension of the cut, with out-of-roundness less than 0.001 in. The 8½-in. ring, with a relatively thin section of 0.250 in., sprung 0.008 in. when opened; but, checked against available records of a bearing manufacturer, this 0.008-in. distortion was less than the normal 0.015 in. after conventional oil quench and temper.

trodes which carry a total connected load of 234 kw. Neutral salt is used in the preheat and high heat (austenizing) furnaces, with a low temperature drawing salt in the isothermal quench bath and drawing furnace.

Following the draw, fixtures of work are conveyed into the wash tank and followed directly by rinsing; work is dried by rising heat as the fixtures return over the battery of furnaces, finally reaching the loading end where racks are removed and the fixtures reloaded. Over 1600 bearings per hour, 2.836 in. o.d., can be completely processed in this equipment, yet floor space for the complete set-up is about one-third of that required for any other method investigated — occupying only 34x15x15 ft. including

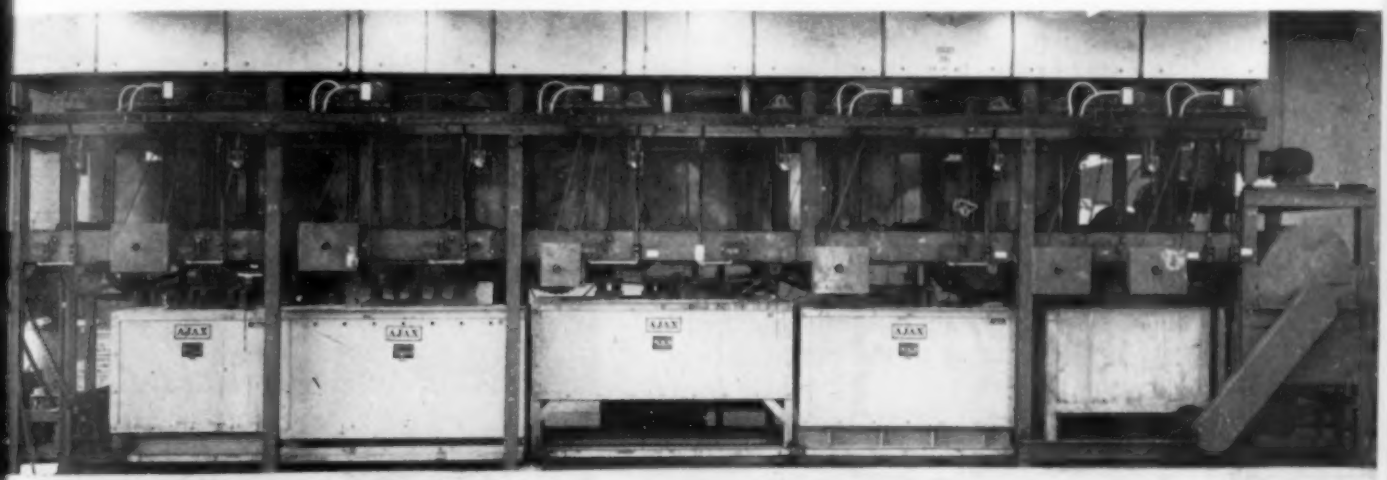


Fig. 4 — Completely Conveyorized Salt Bath Furnaces at Jack & Heintz for Isothermal Hardening of Mechanical Bearings. Transit from left to right. Fixtures, loaded with bearing races, are transferred automatically from one bath to the next, and returned on a track in the hood, overhead, to be unloaded at the loading station

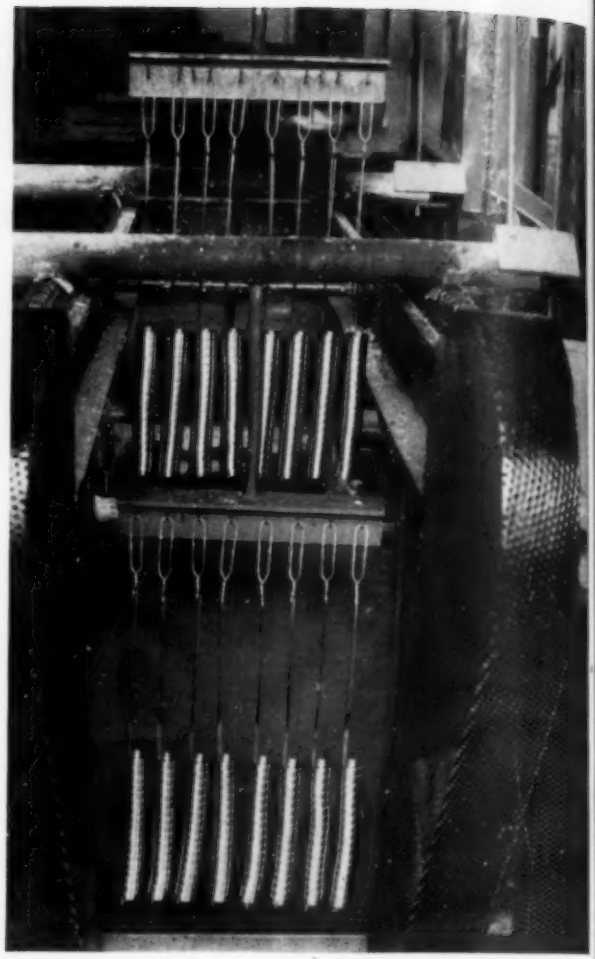
Floor Space Requirements

Accordingly, the completely conveyorized salt baths shown in Fig. 3 and 4 were installed for continuous operation through preheat, hardening, isothermal quenching, drawing, wash-rinse and drying. Bearing races are now stacked in a pile, and hung on simple fixtures made of heat resisting wire. Ten fixtures, each loaded with 22 of the 1.378-in. bearings, can be racked on one horizontal cross bar which is part of the conveying mechanism (Fig. 5). The loaded fixtures are then automatically carried through the following series of heat treating operations: Preheat at 1350° F. for 3½ min.; high heat at 1580° F. for 6½ min.; isothermal quenching to 500° F. for 2 min.; air cool; drawing at 350° F. for 7½ min. All these operations are performed in liquid baths heated by closely spaced immersed elec-

the electric control equipment but exclusive of the ventilating system. Absence of excessive fume permits the furnaces to be near the precision grinders employed in operations both prior and subsequent to heat treating — thus establishing a flow of parts entailing the least possible handling in process.

The conveying mechanism automatically transfers and moves the fixtures through the successive stages of the process as shown diagrammatically in Fig. 3. Horizontal racks, holding the work-laden fixtures, rest on two moving conveyor chains *A* which are driven (at a rate of speed adjustable from 1.5 to 4.5 in. per min.) over the top of the furnaces. (Chain *A* returns beneath the furnaces.) When the racks of fixtures approach entry or exit of any operations, transfer mechanisms *B*, *C*, *D*, *E*, *F* and *G* are actuated by limit switches and either lower or raise the

Fig. 5 — Bearings Are Strung on a Hooked Wire, Which in Turn Is Hung From a Cross Bar on the Mechanism for Conveying Them Through the Heat Treatment Baths



fixture as required. These transfer stations, each individually driven by speed reducers, consist of two matched chains spaced to engage the racks at their extreme ends, and are designed so that transfer time from bath to bath is very rapid. One exception is transfer point *E*, which pauses for the necessary air cool between the quench and draw baths. Return chains *H*, powered by the main drive which also runs conveyer *A*, pick up the racks after the rinse operation and convey the work back overhead to the starting end of the unit, where a single operator loads and unloads the fixtures.

All movements are always coordinated and are electrically as well as mechanically interlocked to assure perfect sequence and duration of each step throughout the cycle. This conveyorized handling assures complete processing of each piece. It is physically impossible for any errors to occur that formerly were attributed to manual effort — such as failure to draw a batch of quenched races. With the loading and unloading stationed at the same end of the unit, manual operations are greatly simplified and confined to a small area, thus adding to the compactness of the installation.

Labor Requirements

The previously used method required three men on the furnaces, two girls for racking and unracking, and four operators in the inspection department for 100% hardness testing. It is now possible to handle approximately 325% greater production (up to 425 lb. of bearings per hr.) with only two men and two girls, one of whom is able to check the hardness since it is only necessary to Rockwell one piece from the top and one from the bottom of each rack. The bearings consistently register C-63 to 63½.

Rejections with the old method were about 10 to 15%, and frequently a second drawing operation was necessary to obtain the specified hardness. In six months of operating the new equipment there has not been a single bearing which failed to meet specifications due to improper heat treating.

Contrasted with the slightly scaled and discolored surface resulting from the former processing (which entailed either sandblasting or pickling before grinding), the bearings now show no signs of scaling and have a very uniform black finish. No evidence of decarburization has been disclosed in regular checks. The micrographs of Fig. 6 illustrate typical results consistently obtained. This inherent feature of salt baths to fully protect the work from oxidation and decarburization is perhaps one of the strongest points in favor of liquid bath treatments. It certainly appears logical to control the atmosphere effects by simply immersing the work where it is sealed from contact with air.

It is also of interest how one seeming disadvantage — namely, that of salt drag-out — is utilized to a degree not short of being unique. While it is unavoidable that work withdrawn from a bath must carry some adhering liquid salt on its surfaces, it is nevertheless this very thin molten film which protects the surface metal during its brief exposure to air prior to entry into the next furnace. Since all salts used in the process are soluble in water, they can be readily removed from the work in the wash-rinse tank, where even minute areas such as small holes or recesses caused by converging radii on small pieces, as shown in Fig. 7, are cleansed without difficulty. It is only necessary to oil the parts before releasing them to the shop for final grinding.

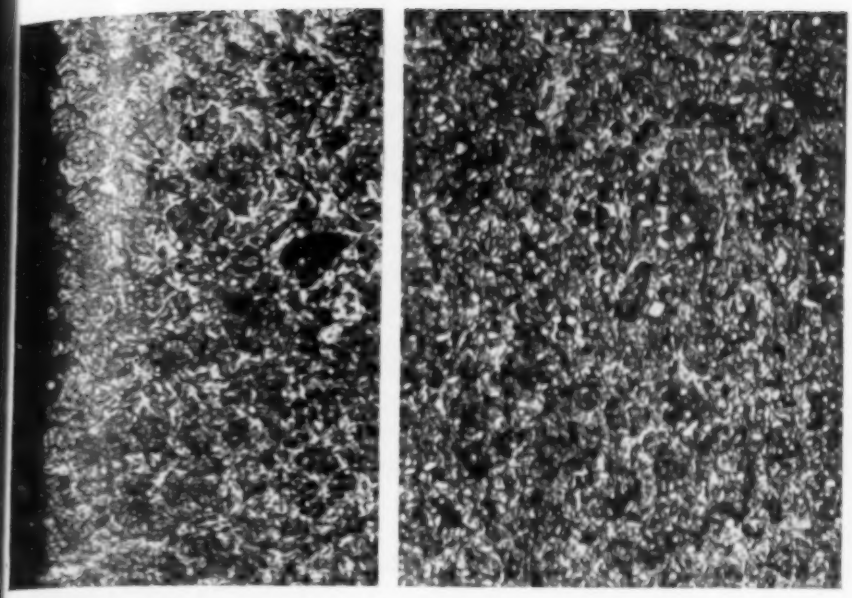


Fig. 6—Transverse Section of 52100 Bearing, Edge and Center, Isothermally Hardened. Magnified 1000 dia., etched with 2% nital

In the machining of this bearing steel, carbide-tipped tools are used, and only 0.005 to 0.010 in. is left for regrinding after heat treating. The martensitic structure obtained by isothermal treatment, with a fine A.S.T.M. No. 11 grain size, has improved grinding conditions to a degree where wheels need be dressed only half as frequently, and two passes now grind as much as three passes on the previously obtained structure. Furthermore, the ground finish is superior to former finishes.

One of the most noteworthy improvements over quench and tempering is in the reduction of distortion shown in Table II. It had been necessary, as previously stated, to quench the larger bearings one at a time in a press. This practice has been entirely eliminated. Races measured before and after heat treatment do not incur more than 0.0005 or 0.001 in. variations on the 1.2597 and 2.8346-in. bearings respectively. This slight distortion on rings hung loosely on fixtures and treated *en masse* is directly attributable to the isothermal technique. By avoiding the sudden and irregular increase in volume below the martensite formation point, and by uniform heating in the initial austenizing bath, minimum physical distortion occurs in any dimension. Further, regulation of the rate of temperature change through the work controls the transformations without incurring excessive quenching stresses which result in cracking.

Operating temperatures are extremely uniform, held within 5° F. of the control point, throughout all the baths in this line-up because the molten salt is circulated vigorously by the "motor effect" of the closely spaced electrodes. Temperatures are held even closer (±3° F.) to the control setting in the quench, for a mixer is incorporated into this unit; temperature build-up is prevented by a blower which is automatically

Table I — Comparison of Costs for Two Methods of Heat Treating 2.8-In. Bearing Races of S.A.E. 52100 Steel

Item	Previous Quench and Temper Method	Present Isothermal Heat Treatment★
Net weight of bearings processed	144 lb. per hr.	425 lb. per hr.
Rejections due to improper heat treatment	10%	None
Output corrected	130 lb. per hr.	425 lb. per hr.
Operating cost‡	$\frac{\$0.65}{130}$ = $0.005 per lb.	$\frac{\$5.29}{425}$ = $0.0124 per lb.†
Heat treating labor	3 men @ 1.20 2 girls @ 1.05 $\frac{\$5.70}{130}$ = $0.0438 per lb.	2 men 1½ girls $\frac{\$3.98}{425}$ = $0.0093 per lb.
Rockwell testing; labor	4 Testers @ 1.05 $\frac{\$4.20}{130}$ = $0.0323 per lb.	½ girl $\frac{\$0.53}{425}$ = $0.0012 per lb.
Operation prior to final grind (sandblasting or pickling)	$\frac{\$3.50}{130}$ = $0.0269 per lb.	None
Die press quenching	$\frac{\$6.93}{130}$ = $0.0533 per lb.	None
Total cost per pound	$0.1613 per lb.	$0.0229 per lb.
Total cost per race	$0.0417 per race	$0.0059 per race

★Preheating, austenizing, quenching and drawing.

†Does not include maintenance cost; however in the six months of operation, maintenance has been negligible.

‡Includes power for heating and conveyor, salt losses, wash-rinse water.

Fig. 7 — Small Parts of 52100 Steel (Pilot Bearings and Pivots) Are Martempered by the Tray-Load. Full size

operated from a potentiometer control instrument, thus cooling the outside surface of the steel pot and readily dissipating the heat carried over by the incoming hot steel.

Adaptability of Equipment

Smaller pilot bearings and pivots, Fig. 7, also of S.A.E. 52100 steel, receive the same processing as the larger bearings with the same uniformity of results. However, a different type of fixture is used in which two perforated metal trays, each holding approximately 250 pieces, are tiered one above another and rigged to a supporting frame that hooks on the horizontal conveying bar. The uniformity of the process permits testing of only 1% of all parts processed to assure Rockwell C-63 to 63½. These pivots, which undergo six machining operations prior to heat treatment, are of interest since they contain small drilled holes and surface recesses; nevertheless, each piece is uniformly heated and is washed clean of adhering salt in the final step of the processing.

S.A.E. 4340 and S.A.E. 4130 steel parts are also hardened with the same equipment. Their treatment is in accordance with time-temperature cycles planned with the aid of S-curves. They receive another variation of isothermal processing — in fact are austempered by the process first described in 1930 by E. S. Davenport and E. C. Bain of U. S. Steel Corp. The cooling curve of a typical piece, surface and center, is shown in relation to the TTT curve for this steel in Fig.

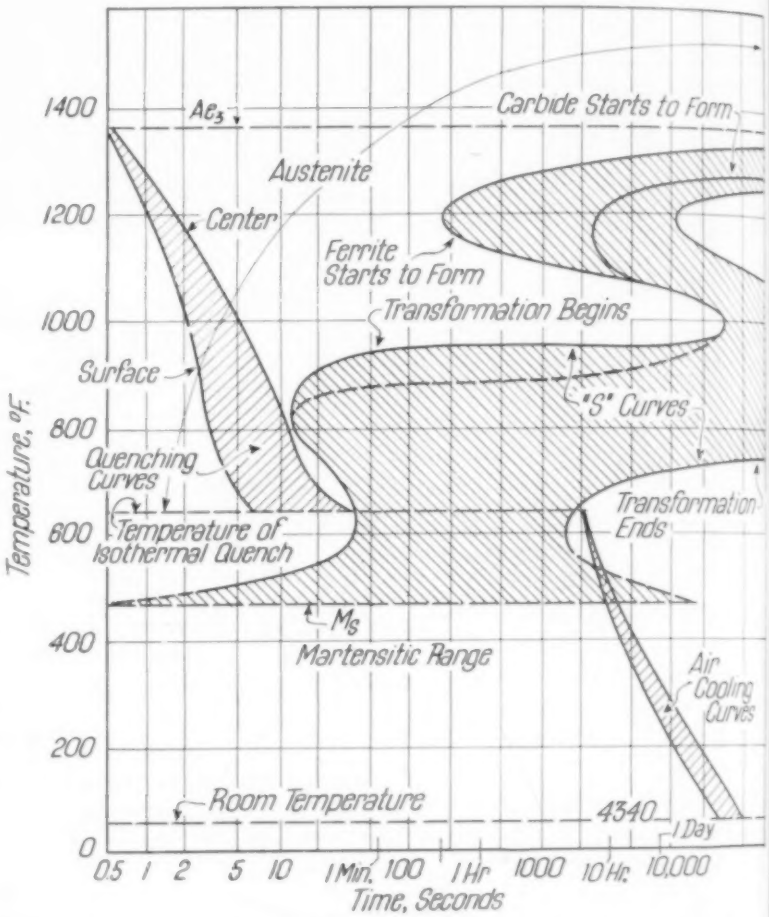


Fig. 8 — Cooling Curves of Surface and Center of Typical Part of S.A.E. 4340 Steel, Austempered by Holding in Bath Long Enough for Complete Transformation (Austenite to Bainite) to Occur

Table II — Distortion of S.A.E. 52100 Bearing Races by Two Methods of Heat Treatment

O.D. of Outer Races Before Heat Treatment	Average Distortion After Heat Treatment	
	Quench and Temper Method	Isothermal Method
0.8750 in.	0.0010 in.	0.0005 in.
1.2597	0.0010	0.0005
1.3780	0.0010	0.0005
1.5747	0.0010*	0.0005
1.6535	0.0015*	0.0010
2.8346	0.0030*	0.0010

*Die press quenched

8. Formation of a true martensitic structure is avoided in the quenched product. It will be observed that work is initially quenched from the austenizing temperature into an isothermal bath maintained considerably above Ms, where martensite forms in this steel. The length of stay in this quenching bath is sufficient not only to equalize temperature between outside and inside of the

piece, but also to permit the steel to transform entirely. The resulting structure is known as "bainite"; it may then be cooled to room temperature without incurring any further microstructural changes. On the work processed in this manner no noticeable quench cracks were discernible; distortional effects are negligible.

Variations in temperature-time cycles for isothermal treatment of the S.A.E. 4340 or 4130 steels, as well as other steels with similar critical cooling rates, are quickly attained for processing in the same equipment by a simple alteration in the control point settings on the pyrometer controllers and by a few adjustments to the conveyer drive mechanisms and transfer stations. Transfer mechanism *E*, Fig. 3, which removes fixtures from the isothermal quench bath and routes them to the draw bath, is especially designed so it can be adjusted for either the martempering treatment or the austempering. It can be adjusted from the longer routing *a* (allowing for a 2-min. quench and subsequent air cool prior to draw, when martempering S.A.E. 52100) to the shorter routing *b* (a 28-min. quench with fast transfer to the draw furnace when austempering S.A.E. 4340 and 4130).

With such wide adaptability of the new equipment in handling a variety of parts made of different steel analyses, plus the relative simplicity of obtaining desired physicals uniformly in mass production, Jack & Heintz production men viewed the heat treating department's facilities as another technological accomplishment in the application of one of metallurgy's newest heat treating tools. An extraordinary number of advantages have been disclosed: Elimination of decarburization, work with practically no distortion, small space for the equipment, reduced personnel, least handling in process, no rejects, uniform hardness of product, absence of scale, a fine grain structure, better finish, and improved grinding operations.

Bits and Pieces

"Bits and Pieces" is a department for practicing metallurgists and metallographers, and they are invited to send in short notes about practices that have been found desirable. An book of your choice is offered for publishable items.

A Non-Destructive Method for Detecting White Layer On Nitrided Steel

DIFFICULTIES encountered in removing the "white layer" from nitrided gears led us on a search for an easy method to determine when we had entirely removed it during grinding or lapping. Its removal is necessary for performance of highly stressed gears, otherwise it will cause flaking of the surface and possible gear failure during service. To be certain that this white layer, which is about 0.001 to 0.0015 in. thick, is removed, dimensional inspection before and after grinding or lapping was required, but this is difficult and may be misleading in such places as the sides of gear teeth.

The following etching solution has therefore been developed and been found to indicate very successfully those areas where white layer is present:

250 cc. H_2O (distilled water)
109 g. $(NH_4)_2S_2O_8$ (persulphate)
1 g. of "naccanol" (wetting agent)
10 drops of a saturated solution of NaCNS (sodium thiocyanate)

The method of applying it is as follows:

Clean the surface thoroughly with any suitable degreasing solvent such as tri-chloroethylene. When dry, apply the etching solution with a brush. The areas of white layer are not attacked by the etchant, and the areas which have no white layer are colored a uniform black. There are no special instructions necessary except we recommend that it be applied with a brush or cotton swab.

A word of caution might be inserted here for the interpretation of results. If the white layer areas have been stressed enough to break up the continuity of the layer, it will etch dark, due to the fact that the etchant penetrates through the tiny checks in the white layer and gives the impression that the whole area is etched black. This has been found to be true of shot blasted or

Temper Colors Vs. Temperature for Various A.I.S.I. Types of Stainless Steel

	302; also 18-8 (Modified)	316	310	310	410	446	302	"Cutlery Stainless"	430 302	302	410	Carbon Tool Steel
Source of data	Zmeskal *(a)*	Metallurgicus		Dobkin *(b)*	McAdam & Geil *(c)*			Monypenny *(d)*		Sartorius *(e)*	Humberger *(f)*	Bethlehem
Finish on samples	Electropolished, clean	Polished, oiled		Polished, clean	Metallographically polished, clean			Polished		Filed	Smooth machined	Ground
Minutes at heat	60	60	60	60	60	60	60	not given	60	5	30	not given
Color	Temperature (°F.) For Development of Temper Color											
First straw	600	500	600		450	625	560					
Straw	750	750	750					600		840		380
Brown (bronze)	800	900	900	900	810	1165	1180	750	600	1020	665	420
Purple	900	1000	1000	1000				925	750	1110		460
Cobalt blue	1000	1100	1100	1100	1275	1300	1380	1060		1200	825	500
Pale blue (gray)	1100	1150	1150	1200				1200	840	1290	915	580
												660

(a) Otto Zmeskal, Universal-Cyclops Steel Corp., Bridgeville, Pa.
(b) Herbert Dobkin, Turbo Engineering Corp., Trenton, N. J.
(c) McAdam & Geil, *Journal of Research*, National Bureau of Standards, Vol. 23, July 1939 (RP 1221).
(d) J. H. G. Monypenny, "Stainless Iron and Steel", 1931, pages 401 to 405.
(e) R. G. Sartorius, National Lock Washer Co., Newark, N. J.
(f) Frank Humberger, Wm. Powell Co., Cincinnati.

tumbled surfaces, as well as the surfaces of gear teeth that have been in service where the continuity of the brittle white layer has been broken. Frequent microscopic examinations should be made to check the accuracy of the method and the ability of the operator to use it.

As soon as the part has been inspected the reagent should be wiped off with absorbent cotton, washed, and dried. This is to prevent any subsequent corrosion. The reagent can be applied to any finished part without injury. Gear teeth which have been discolored may be used without brushing off or otherwise removing the discoloration. (George Weiss and M. S. Burg, Metallurgical Dept., Dodge Chicago Plant)

Temper Colors on Stainless Steels

In this section of the January issue I remarked on my inability to find any information on temper color vs. temperature relation for stainless steels, and suggested that those having such data send it in for the general good.

Apparently this question has been of general interest, because several answers have been received, giving results of tests. Two publications on the subject were pointed out by contributors, one of these, by McAdam and Geil (see the footnote to the table) being very comprehensive; it gives time-temperature relations for film thickness — a measure of the color — on a wide variety of common, tool, and stainless steels.

The tabulation summarizes the several contributions and includes data for 1-hr. colors from McAdam and Geil. I have exercised my judgment in interpreting the various terms used in describing colors, and as a base-line have included the colors for carbon toolsteel from the colored chart published by Bethlehem Steel Co.

It will be noted that there are some definite disagreements; these may be due to the manner in which the tests were conducted by the various individuals, or to their or my different names for the colors.

Thanks indeed to all who answered my request; a future generation will, I trust, only have to turn to "The Book of Stainless Steels" to get this information (Editor Thum please note!).

Metallurgicus

Storage Jars for Bits and Pieces

Every laboratory has a junk drawer. We've cleaned up ours and gotten rid of our unserviceable and unsightly catch-all.

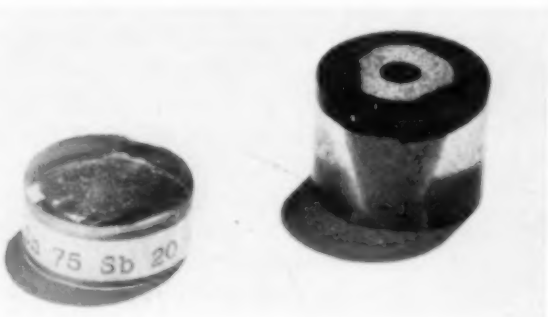
We use small screw-cap jaws (the Kodak

prepared-fix jars do the job — in two handy sizes, too). Nail or bolt the screw-cap to the underside of a tool shelf, and then screw the jar into place. Each jar can hold a particular item such as screws, bolts, nuts, small sample polishing clamps, and other odds and ends. In this way, the material is nicely segregated, the contents of each jar can be seen at a glance, yet it is out of the way. (H. M. SHANNON)

Preservation of Samples

LUCITE is an excellent preservative for polished and etched specimens. If the specimen is placed near the top of the mount, and a relatively thin coating of lucite covers it, the specimen may be viewed up to 100 magnifications.

The mount can also enclose a paper slip identifying the specimen. This scheme, shown at left in the engraving, has done away with repolishing, year after year, for classroom work.



Lucite, while having many advantages for work in industrial laboratories, is too soft for polishing by beginners. After several polishings the soft lucite wears away leaving the alloy in relief. This condition of course makes focusing difficult.

An improvement in mounting is as follows: First add to the mold hard bakelite and then fill the remainder of the mold with lucite. This gives a hard surface to be polished and permits one to see the bulk of the specimen through the transparent lucite. (CHARLES Y. CLAYTON, Metallurgical Dept., Missouri School of Mines)

Agitating Quench Baths With Dry Ice

FREQUENTLY, in small heat treating laboratories or when conducting certain experiments which involve oil quenching, the facilities are not at hand for circulating or cooling the oil.

Agitation and cooling can be done quite easily and at the same time by merely dropping pieces of dry ice in the bath. The dry ice sinks to the bottom of the container and the evolution of gas causes a tremendous amount of movement in the oil. If it is desired to localize the action the dry ice should be added in one large piece; small pieces will give a general agitation throughout the entire bath.

The CO_2 gas given off, being heavier than air, also forms a protective blanket over the oil and prevents oil flashing during the quenching process. (A blanket of CO_2 might be used to prevent oil from flashing during a martempering operation where the oil would have to be at a higher temperature.) (JOHN S. JACKSON, Battelle Memorial Institute.)

"Tinning" a Bearing Before Babbitting

SOME REMARKS on the preparation of a bearing for lining are in order, since no bearing is better than the bond between backing and lining. The ideal is to have a chemically clean surface which is then tinned with the proper tinning metal. However, in large bearings, the workman usually grinds the surface with a hand grinder until he thinks it is clean. To check on this, brush on a mixture of copper sulphate and water with a few drops of sulphuric acid in it. Copper will deposit on the surface if the bearing is chemically clean. This process is repeated until the bearing has a complete copper coating. The bearing is then washed with a little household ammonia to neutralize any acid and to remove excess copper, and then rinsed with water and fluxed with a zinc chloride acid flux. (We found that commercial fluxes were variable and subsequently established either "Grasselli No. 1" or "Bruko" as our standard. The use of molten zinc chloride is not recommended.)

The bearing is then placed into the molten tinning metal.

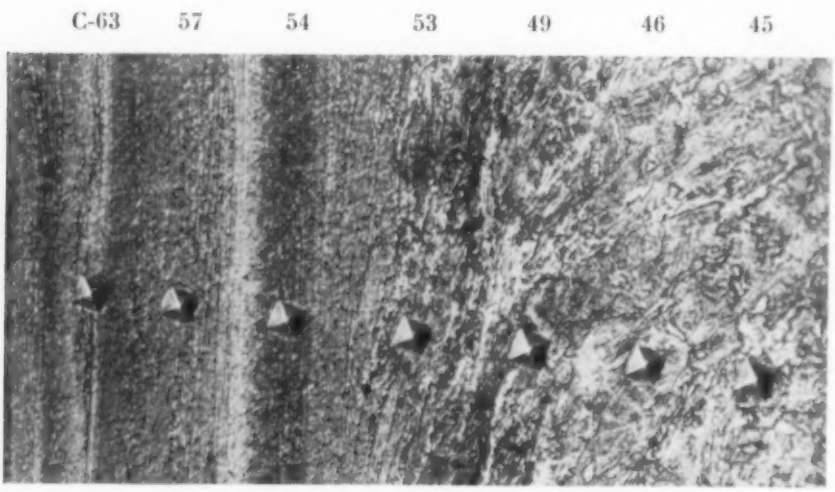
For tinning lead-base bearings, we use 20% tin and 80% lead. For tin-base babbitts we still use pure tin for tinning. This tinning metal is heated between 550 and 600° F. The bearing is then totally immersed in the bath until it reaches the temperature of the tinning metal. While the bearing is in this tinning bath, the jigs and fixtures are heated to between 300 and 600° F., depending on the size and shape of the jig and the bearing, and finally on the thickness of babbitt to be poured. (Thin babbitt should have hotter jigs.)

The bearing is then taken out of the tinning bath, assembled in the jig, and the babbitt is poured. This must be done quickly so that the heat in the bearing is not lost. If the tinning

metal freezes on the bearing, it will not be remelted by the babbitt and a bond will not be obtained between the two metals. This idea of keeping the tin molten on the bearing proper is important. We know of a number of cases where companies have gone to elaborate lengths to tin bearings and then allowed the tin to freeze. Unfortunately, a bond is impossible when the tin is not molten; this is a matter of long experience, and we consider it one of the most important factors of making a bearing. (T. E. EAGAN, Chief Metallurgist, Cooper-Bessemer Corp.)

Hardening by Tool Abrasion

TROUBLE developed in broaching a bored hole in a part made of S.A.E. 3312 steel, cycle annealed to Rockwell C-18. The broach was made of high speed steel. The boring tool used in the preceding operation was a sintered carbide tool ground with axial and radial negative rakes and traveling at 700 ft. per min., surface speed. A hardness test on the bored surface was Rockwell C-40 and a 15N superficial hardness equivalent to Rockwell C-55. The photomicrograph and micro hardness tests tell the rest of the story.



Outer 0.009 In. of Surface Overheated by Dull Drill. Forging originally annealed to C-18; actual hardness as noted. Section etched with 1% nital, magnified 500 diameters

A cross section through one of the troublesome holes showed a hardened structure 0.025 in. deep. The outer portion, including a severely cold worked layer, shows part of the hardness traverse and the micro-hardnesses converted to C-scale are noted in the line of figures above the engraving.

This surface was much too hard to broach with high speed steel. Apparently the carbide boring tool had been used long after its cutting edge had worn away, but the only visible evidence was a burnished surface and a slight change in dimension of the hole. Even a carbide tool of the type used a few years ago probably would have crumbled under these conditions but the negative rake tool, with its well supported edges, continued to push its way through the metal after true cutting action had stopped. A high speed steel tool would have burned up long before this stage was reached.

Of course, a very small amount of cold work is quite common on machined surfaces. This sample shows what can happen under extreme conditions. (JOHN HILL, Metallurgical Laboratory, and C. W. DIETZ, Heat Treat Dept., Continental Motors Corp.)

Proof Testing of Control Cables

CONTROL CABLES connecting ailerons, rudders and other fuselage units to servo-motors must be individually proof tested, after attachment of turnbuckles and end shackles. This has ordinarily been done on a stretcher bench long enough for the longest cable, the operators testing one at a time, and standing idle for the required duration of the proof load — sometimes 3 min. An automatic device has been developed by our electrical department that cuts the time at least half. In this new device, the electrical switches are placed at the power head; the tail carriage (adjustable by stops for correct cable length) carries equalizer bars so more than one cable can be tested at a time, and an ordinary beam balance weighing device to measure the loads.

The actual operation of the new control is as follows: After placing the cables in position, the operator puts the machine in rapid forward motion by pressing a button. When the cable becomes taut a relay opens automatically, reducing the movement to slow speed. As the required tension is reached, and the beam on the balance rises, a photo cell stops the tension head, and a second relay starts a timing device. This in turn opens another relay after the required interval has elapsed, which reverses the machine and slacks off on the cables. Finally the machine is automatically stopped by a limit switch after it has moved far enough to free the cables. (AVERY MCBEE, Glenn L. Martin Co.)

By Given Brewer
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The Electric Strain Gage

PREDICTION of the behavior of large structures under load often necessitates a valid stress analysis. In certain fields of manufacture, wherein the product is simple or results from a long period of evolution, each succeeding design can be based on the extrapolation of data accumulated over years of experience; in such cases the basic test data (experience) are so close to the design conditions that no recourse to intermediate calculations is necessary. In the structural design of large aircraft, bridges and ships, on the other hand, a broad gap exists between basic test data and the strength of the final design. From the standpoint of economy it would be ideal if the strength of the largest and most complex structures could be predicted from the simple laboratory tensile test, but at its present stage of development stress analysis is not sufficiently powerful to bridge this gap. It therefore becomes necessary to conduct static tests of scale models or full size sections of the proposed structure in order to predict its final strength.

As it is easier to predict stresses (unit loads) within a structure under load than the resulting strains (unit deformations), and as the values of allowable stress can be determined with more facility than can allowable values for strain, methods of stress analysis, as the name implies, are confined almost entirely to considerations of stress. However the structure in resisting the applied load must deflect and each component part must deform. Outwardly, then, the structure gives evidence of the stresses acting within it by deflecting as a whole and by strains detectable on the surfaces of the component parts. However if methods of stress analysis are to be improved or if analyses already made are to be substantiated it is of importance to determine the stresses within a structure under load. These stresses may be found through the expedient of measuring the surface strains on the structure at the point in question and converting these values of strain into corresponding values of stress, utilizing previously established relationships between stress and strain.

It will be the endeavor of this and subsequent articles to show how this is done for a few elementary although important components. Elementary considerations of mechanics and the relationships between stresses, strains and directions will introduce a description of modern strain gages and their use. Their use, it may be emphasized at the outset, is by no means confined to the stress analyst, but can be and is being extended by engineers of all sorts in a study of new designs, the determination of safe loads on existing equipment, or the investigation of obscure failures.

Any given state of two-dimensional strain may be resolved into symmetrical and antisymmetrical components. In other words, any state of strain may be shown to be composed of a combination of hydrostatic strain and pure shear strain, as shown in Fig. 2. Hydrostatic strain in two dimensions (Fig. 2*a*) is evidenced by a

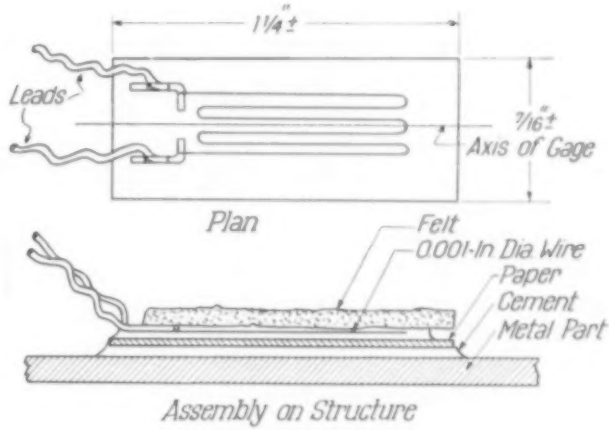


Fig. 1 — Construction of Bonded Wire Resistance Strain Gage and Its Attachment to the Structure

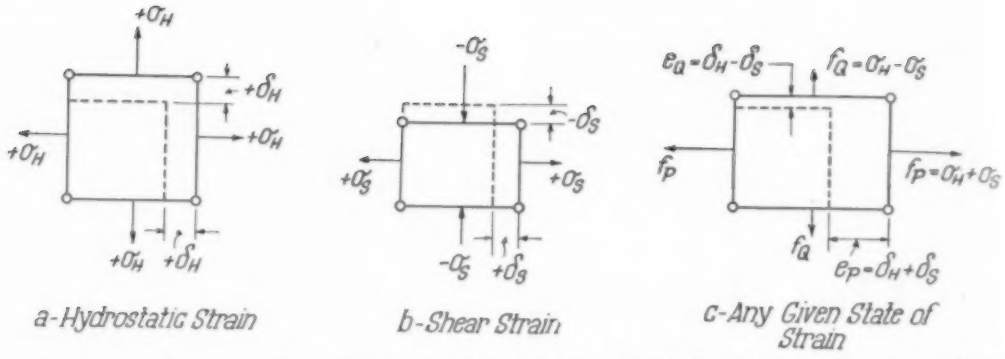


Fig. 2 — Sketch Showing Deformation of Metallic Crystal Under Various Stress Conditions

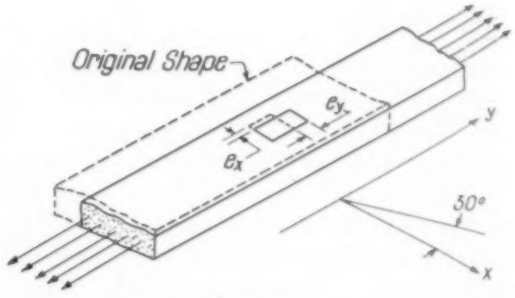
change in surface area of the substance — say a single metallic crystal — with no change in geometrical shape, whereas pure shear strain (Fig. 2*b*) is evidenced by a change in shape of the same substance with no change in surface area. (While the above statements and the diagrams in this paper are, for convenience, shown in two dimensions, the principles involved are strictly true in three dimensions.)

Thus, the resistance to applied stress is derived from the change in atomic spacing within the metallic crystal, and this is evidenced by strain (change of shape and size). What we term the "spring constant" of the metallic crystal is the well known modulus of elasticity *E*.

A relationship between stress and strain found most commonly is in the stress-strain diagram obtained from the simple tension test, as shown in Fig. 3*b*. Therefore, if in a large structure under load — such as a tension member in the framework of a crane — an axial strain of +0.001 in./in. (inches per inch) is recorded upon the application of the load W, as shown in Fig. 4*a*, and if the member be made of steel, the stress may be found from the stress-strain curve for steel (Fig. 4*b*) or may be calculated from

$$\text{Stress} = f_T = e \times E = 0.001 \text{ in./in.} \times 30 \cdot 10^6 \text{ psi.} = 30{,}000 \text{ psi.}$$

Referring to Fig. 3*c* it can be seen that the metallic crystals comprising the tension member have elongated in the direction of the tensile stress but have contracted at right angles to the applied stress. (This change in dimension at right angles to the principal stress is most evident in the plastic range, as in the "necking down" of a tension test piece at and near the plane of fracture. The ratio of lateral to longitudinal deformation in the *elastic range* is called Poisson's ratio, is approximately ⅓ for steel, and will be noted in these articles by the symbol μ.) This dimensional change will be shown if a strain gage is affixed at right angles to the axis of the strap; it will indicate a negative strain equal to the axial strain multiplied by Poisson's ratio, or $e_x = -0.000333$ in./in.



In this example it is obvious that no external stress exists at right angles to the applied tension stress in the strap, yet a compressive strain does exist by virtue of the presence of tension in the normal direction. In more complex structures where the direction of the principal stress is not always known, and particularly in structures

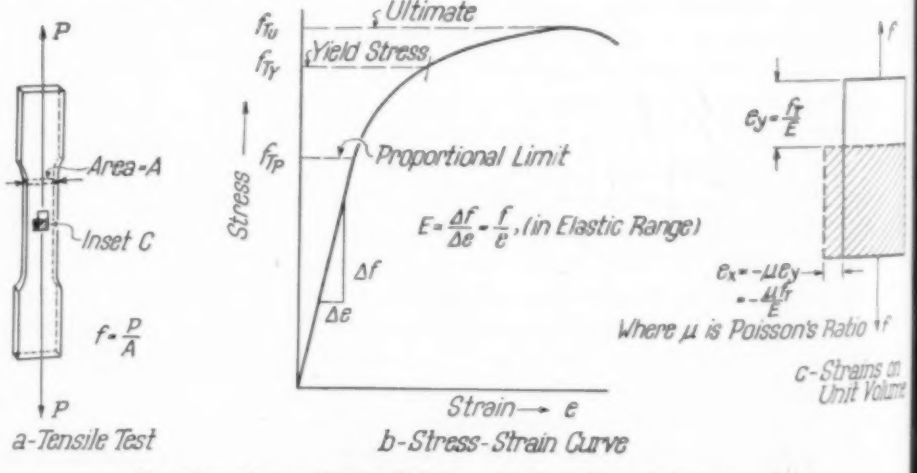


Fig. 3 — Stress-Strain Relationships for Simple Tension Test

where two-dimensional stress fields exist, the stress in a given direction cannot be determined by simply multiplying the measured axial strain by Young's modulus of elasticity. From the simple tension strap it can be seen that if all of the facts were not known concerning the loading of the member it might be possible to interpret the compressive reading of the lateral strain gage as evidence that a compressive *stress* existed in this direction, an interpretation obviously in complete error. Indeed, in the tension strap a plane of zero axial strain can be found at 30° to the x axis,* yet at this same plane a finite tension stress equal to +7500 psi. exists.

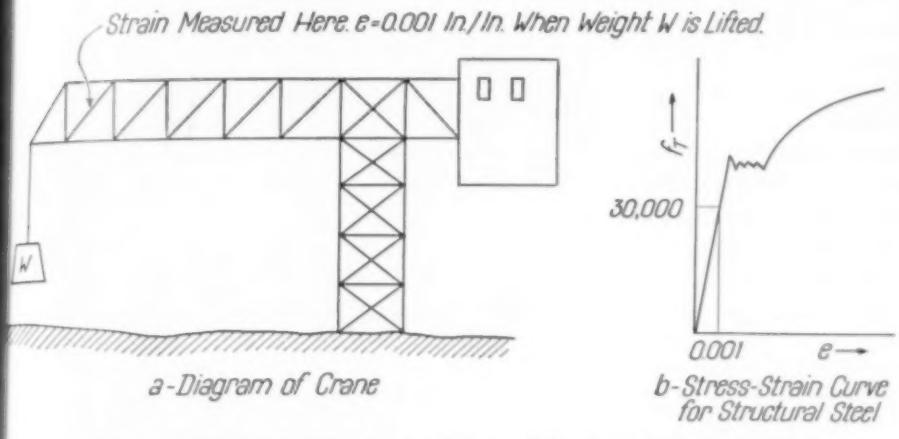


Fig. 4—Measuring Strain in Tension Member of Crane Boom

Single strain measurements must therefore be made with a complete understanding of the loading conditions if the stresses are to be accurately determined thereby. In the analysis of structures wherein two-dimensional stress fields exist, such as the shear beam of an airplane wing (Fig. 5), strains must be determined in three separate directions in order to determine the principal stresses and their directions. (The methods of analyzing two-dimensional stress field by utilizing strain rosettes will be outlined in a later article in *Metal Progress.*) Thin sheets, such as exist in shear webs or beam flanges in aircraft, have only a moderate degree of stiffness and the metal bends out of plane or "waves" to some degree under the applied stress (Fig. 5). Presence of such waves or buckles precludes the accurate measurement of strain with mechanical types of strain gages; these bridge the waves, yielding a completely invalid result.

The electric strain gage overcomes many of the handicaps of the mechanical strain gage as a means of determining stresses within a structure. The wire type of electric strain gage, backed with a compensating gage, will yield a completely valid strain record of conditions at that spot, whether or not the sheet has buckled; the electric gage may be readily attached in remote places; it may be read electrically at a distance from an otherwise inaccessible location; it does not creep or slip under vibratory stresses; it is not subject to hysteresis and it records static or dynamic stresses with equal facility. Furthermore electric gages may be accurately compensated for temperature changes, regardless of the metal used for the structure, whereas mechanical gages compensated for one metal are uncompensated for any other.

This remarkable versatility and usefulness of the electric bonded wire strain gage has received full attention in the recent technical and trade literature, and only a few simple applications will be discussed in this article.

Construction of the Gage — Although the fact

*"Determining Principal Stresses by Use of the Equilateral Strain Rosette", by Given Brewer, *Aero Digest*, Jan. 1, 1945, page 91.

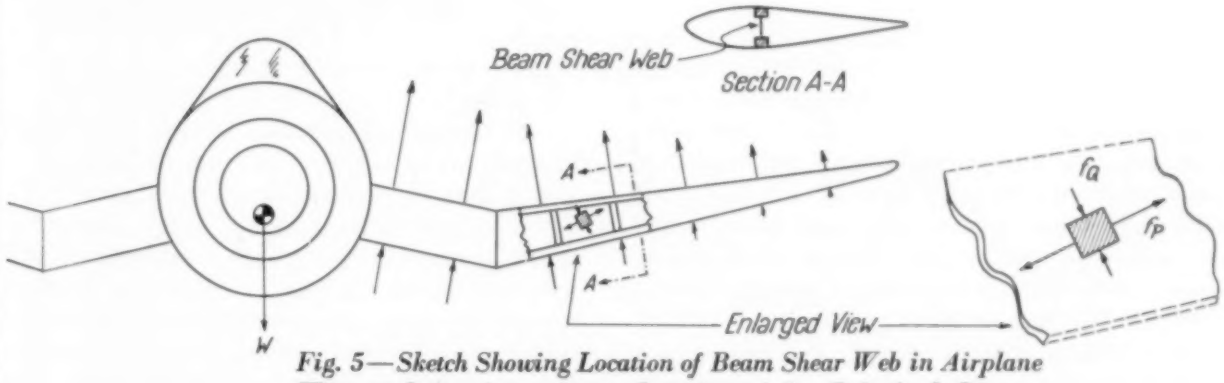


Fig. 5—Sketch Showing Location of Beam Shear Web in Airplane Wing and the Approximate Location of Its Principal Stresses

that wire changes resistance when strained has been known for some time (see P. W. Bridgman's article on "Theoretical Considerations on the Nature of Metallic Resistance" in *Physical Review* for 1917, page 269) its application to the measurement of strain in structures by bonding strain sensitive wires to the surface of the metal was made by E. E. Simmons, Jr., of the California Institute of Technology and A. C. Ruge of Massachusetts Institute of Technology. The Baldwin Southwark Division of the Baldwin Locomotive Works has purchased the patent rights to the bonded wire resistance gage and manufactures them under the trade name "SR-4".

The SR-4 gage at its present stage of evolution consists of a fine gridwork of 0.001-in. dia. strain sensitive wire, bonded to a paper base and covered with a felt strip, as shown in Fig. 1 on page 91. The gage is cemented to the surface of the structure at the desired location and the leads are connected to a suitable device for measuring electrical resistance — usually a Wheatstone bridge. As the cross-sectional area of the cement is very large compared to the cross-sectional area of the wires, the latter are forced to stretch or compress exactly the same amount as does the surface of the structure directly underneath. Therefore the surface strains of the structure in the direction of the gage axis will cause equal strains in the wire, equal both as to amount and as to sign (direction). When the wire grid is strained in this manner the total length of the wires is altered (as is also their cross-sectional area, according to Poisson's ratio). Since the resistance of a wire depends not only upon its length but inversely as to its area, it is logical to suppose that the overall resistance of the gage will increase with axial tension strains, or decrease with axial compression strains, and be unaffected by angular shear strains.

We assume that the change in resistance R of the wire is a function only of the change in length L and reduction in area A. Let R_1 be the gage resistance before being stretched an amount ΔL_1 and R_2 be the gage resistance after stretching ΔL. Then it may be shown that

$$\text{If } R \propto \frac{L}{A}$$

$$\text{Then } R_1 = C\,\frac{L_1}{A_1};\ R_2 = C\frac{L_2}{A_2}$$

$$\text{Therefore, } R_2 - R_1 = \Delta R = \frac{CL_2}{A_2} - \frac{CL_1}{A_1}$$

$$\Delta R = \frac{CL_1}{A_1}\left[\frac{1+\frac{\Delta L}{L_1}}{\left(1-\mu\frac{\Delta L}{L_1}\right)^2} - 1\right]$$

$$\frac{\frac{\Delta R}{R_1}}{\frac{\Delta L}{L_1}} = \frac{1+2\mu}{1-2\mu\frac{\Delta L}{L_1}} \cong 1+2\,\mu \text{ (for small strains)}$$

$$= \text{strain sensitivity factor } S \text{ of the gage.}$$

Theoretically the strain sensitivity factor S should lie between +1.6 and +2.0. However other factors as yet unidentified conspire to yield gage factors between +3.5 and —12.1, the gage factor varying with the heat treatment, cold work and analysis of the various alloys used. See the values listed in Table I.

Table I — Properties of Wire Commonly Used for Strain Gages

Name	Nominal Composition	Resistance★	S	Temperature Coefficient†, β		$K \times 10^6$ (Calculated)
				Steel	Aluminum	
Advance, Copel or Constantan	45% Ni, 55% Cu	306	+2.38	—66.2	—37.4	—94.6
Iso-elastic Wire	36% Ni, 8% Cr, 0.5% Mo 3.5% (Mn, Si, Cu & V) 52% Fe	680	+2.82 or 3.50	+471 +600	+515 —	+447.4 —
Nickel			—12.1	unstable		

★Ohms per ft. of wire 0.001 in. diameter.
†Temperature coefficient of resistance $\times 10^6$ in ohms per ohm per deg. Cent., when cemented to the respective metal.

Effect of Temperature Changes

While many tests involve no change in temperature of the metal during the tests, it is well to understand what will be the result of such a change.

It has been found that resistance of the wire, in addition to being a function of strain, is also a function of temperature; this factor, known as the "temperature coefficient of resistance", is noted by the symbol β, and is expressed in ohms per ohm per deg. Cent. A positive coefficient implies that the gage will increase in resistance with an increase in temperature, whereas a negative coefficient means that the gage will decrease

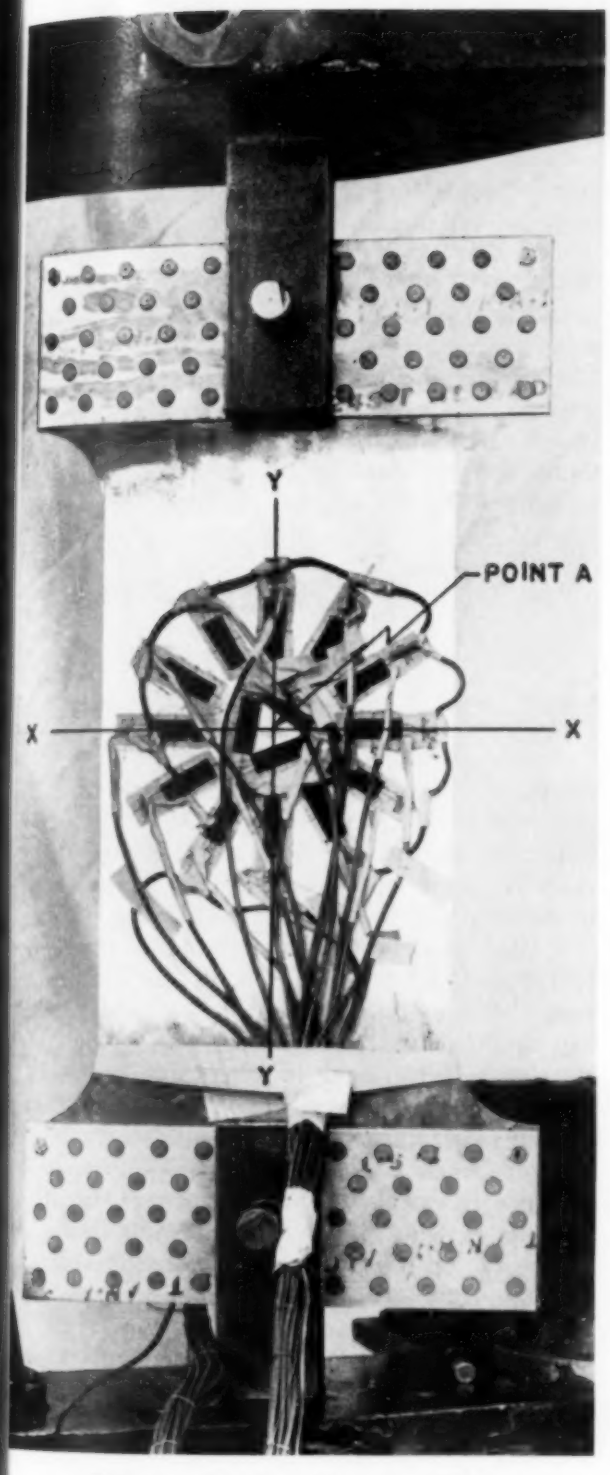


Fig. 6 — Tension Test on Wide Sheet With Gages Attached to Measure Actual Distribution of Strain

in resistance with an increase in temperature. Therefore if a gage is cemented to the surface of a bar of metal a change in temperature will not only change the inherent resistance of the gage wire but the thermal coefficient of expansion of the metal will cause thermal strains in the metal that will also strain the gage wire, causing a further change in gage resistance. Thus the effective temperature sensitivity of the gage when cemented to a certain metal should be in accordance with the relations computed below:

Due to a change in temperature of 1° C., and assuming that gage resistance when free varies in two components, one inherent (due to temperature change) and the other a function of the thermal strain:

$$\Delta t \cdot \beta_{gage} \propto K \cdot \Delta t + S \cdot a_{gage} \cdot \Delta t$$

where t is temperature, Cent.
Δt is 1° C.
β is the temperature coefficient of resistance
a is the temperature coefficient of linear expansion
S is the strain sensitivity factor
and K is a constant

The above is for the gage alone.

If the gage be made of Copel wire and be cemented to an aluminum bar, we have the following expression:

$$\beta_{Aluminum} = K + S\,(a_{Al} - a_{gage}) + S \cdot a_{gage}$$
$$= K + S a_{Al}$$

Inserting numerical values from Table I, and knowing that the linear coefficient of thermal expansion per °C. for aluminum at atmospheric temperatures is $24 \cdot 10^{-6}$,

$$\beta_{Al} = -37.4 \cdot 10^{-6} = K + 2.38\,(24 \cdot 10^{-6})$$

Whence $K = -94.6 \cdot 10^{-6}$ for Copel wire.

Using this value for Copel wire and knowing that the linear coefficient of thermal expansion of S.A.E. steel, while depending somewhat on analysis, averages about $11 \cdot 10^{-6}$ per °C., we can figure β for steel as follows:

$$\beta_{Steel} = -94.6 \cdot 10^{-6} + 2.38\,(11 \cdot 10^{-6})$$
$$= -68.4 \cdot 10^{-6}$$

This figure, which may be measured with precise direct-reading mechanical and optical extensometers, varies between the values of $-66.2 \cdot 10^{-6}$ and $-76.3 \cdot 10^{-6}$

Similar computations for iso-elastic wire ($S = +2.82$) cemented on steel give values of β of $+475 \cdot 10^{-6}$, while the measured value checks very closely at $+471 \cdot 10^{-6}$.

Relative Utility of the Two Types

From the above it is apparent that gages made of copper-nickel wire* when cemented to aluminum alloy bars have only about 7% the temperature sensitivity of iso-elastic wire gages. This at first thought seems anomalous, since the thermal coefficient of linear expansion for iso-elastic wire is almost zero whereas this coefficient for Copel wire is $+14.6 \cdot 10^{-6}$. The desirable

*Baldwin Southwark "A" type strain gage.

behavior of Copel is explained by the fact that its negative temperature sensitivity tends to counterbalance its positive strain sensitivity when thermal strains exist. Obviously, then, the copper-nickel wire will yield more valid results than will iso-elastic wire gages when temperatures change during the test.

Temperature may be completely compensated through the use of a dummy gage cemented to an unloaded structure having the same ratio of mass to exposed surface area as the structure being tested. If the dummy structure is placed near the active one, changes in atmospheric temperature will cause nearly identical thermal strains in the two, and the change in strain recorded by the dummy gage may be subtracted from the total strain recorded by the active gage, thus yielding the correct value of strain, free of thermal errors. Although gages may be built of two wires having compensating temperature sensitivities for a given material, these double-wire gages have proven impractical. Since the coefficient of linear expansion for steel is affected by cold work as well as composition, a compensated gage for all types of steel is virtually impossible.

Table I shows that the resistance per foot of the iso-elastic wire is about 2.2 times as much as Copel, and as its gage factor *S* is 1.3 to 1.5 as much as Copel's; the result is that, for a given strain, an iso-elastic gage will give 3 to 3½ times as much voltage change for a given gage length and equal current. In the measurement of dynamic stresses (where the temperature sensitive properties of the iso-elastic gages are not objectionable, since the temperature cannot fluctuate appreciably during the recording period) the extra gain in voltage is desirable. Wire of this sort is used in Baldwin Southwark "C" type.

The total resistance of the bonded wire strain gage is usually above 100 ohms, so that contact and lead resistances of the recording apparatus will not ordinarily be appreciable factors and subsequent sources of error. Usually the leads can be soldered to the gage. If leads cannot be permanently attached, a plastic terminal containing small wells of mercury can be used for plugging in and out and insure a constant contact resistance approaching zero in magnitude.

The plastic bonding material or cement, as the case may be, serves the dual purpose of picking up the surface strains of the loaded structure by adhesion and transmitting these axial strains to the wire grid, thereby straining it an amount very nearly equal to the movement experienced by the structure. Although the bonding cement must suffer some shear deformation in transmitting these strains, this effect is negligible due to three factors: First, the distance from the plane of the grid to the surface of the structure is very small; second, the cross-sectional area of the plastic is very large with respect to the cross-sectional area of the wires; and last, the bonding area between the wires and the plastic is very large compared to the cross-sectional area of the wires. Analogous to reinforced concrete design, the support offered the thin wires by the surrounding plastic is sufficient to transfer large compressive strains without buckling the wire. This is proven by stress-strain curves, compression or tension, obtained with electric gages which agree exactly with curves obtained simultaneously with precise mechanical gages. Other tests have also shown that properly bonded gages are not subject to creep or hysteresis.

Cements

Various bonding materials, plastics and cements have been studied. Experimental work has included the testing of thermosetting and thermoplastic materials, employing various techniques at different stages of polymerization. The commonly used gages today are bonded to their paper bases (for electrical insulation) by nitrocellulose dope, and are cemented to the surface of the structure to be tested by a similar adhesive.

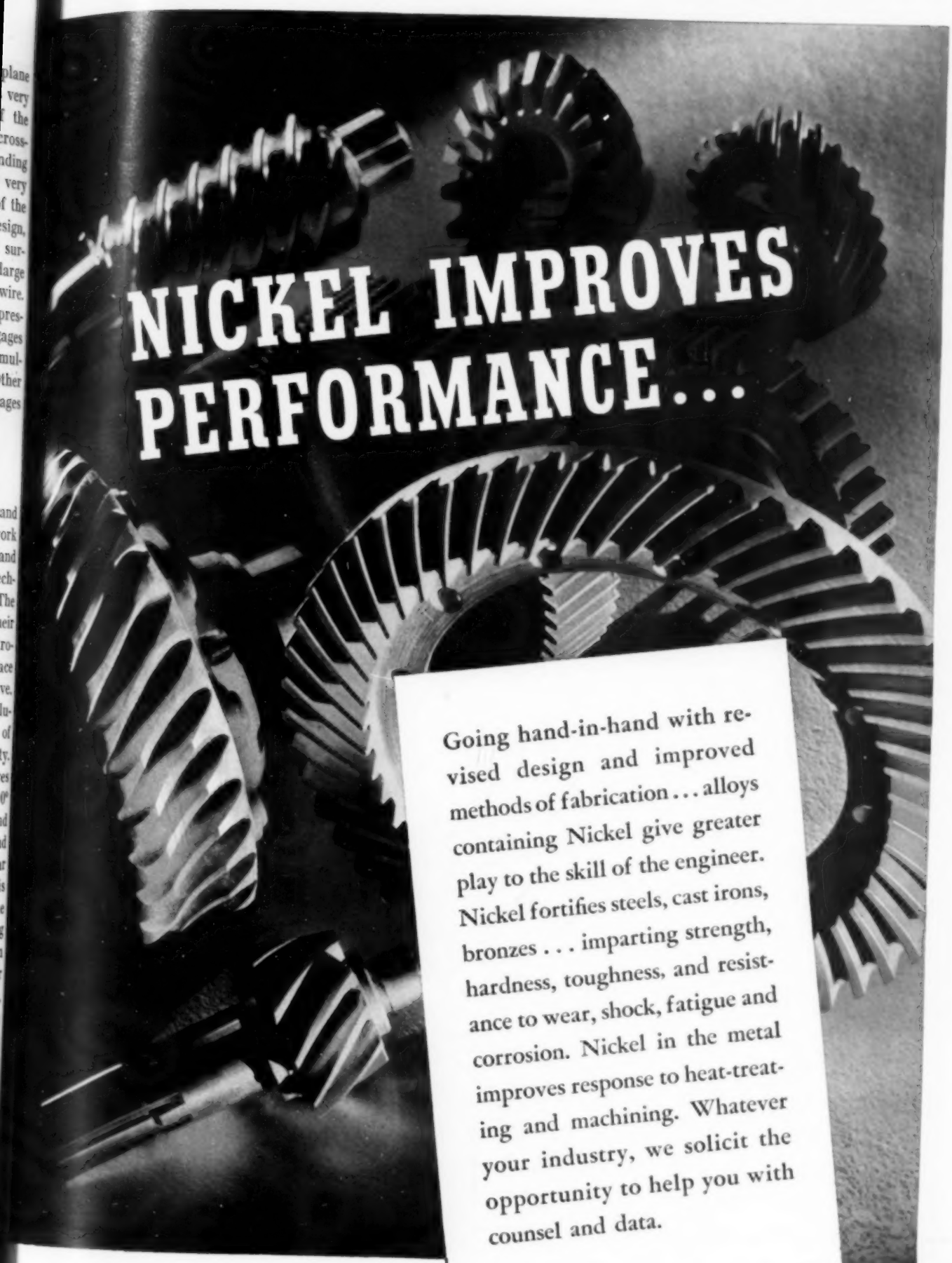
Popular adhesives are Duco cement or celluloid dissolved in acetone, with the addition of castor oil or similar plasticizer to add flexibility. For applications involving tests at temperatures ranging to 300° F. (or for short duration to 500° F.) phenol-formaldehyde bonding materials and special papers are used in the manufacture, and the gage must be baked in place using a similar thermosetting plastic for an adhesive. It is usually advisable to prepare the surface of the structure for the gage by very lightly roughing the surface with 000 or 00 emery paper, and then cleaning with a varnish thinner or a similar solvent. The surface is then brushed with cement, or the gage itself may be lightly wetted with cement and firmly pushed on the structure and allowed to dry overnight before the leads are connected.

References

"Concerning the Subject of Testing," SR-4 News Letter, Vol. I, No. 2; Baldwin Locomotive Works.

"The Development of Electrical Strain Gages," by A. V. de Forest and H. Leaderman, N.A.C.A. Technical Note No. 744.

"Characteristics and Aircraft Applications of Wire Resistance Strain Gages, by A. V. de Forest, *Instruments*, April 1942, page 112.



Going hand-in-hand with revised design and improved methods of fabrication . . . alloys containing Nickel give greater play to the skill of the engineer. Nickel fortifies steels, cast irons, bronzes . . . imparting strength, hardness, toughness, and resistance to wear, shock, fatigue and corrosion. Nickel in the metal improves response to heat-treating and machining. Whatever your industry, we solicit the opportunity to help you with counsel and data.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

Engineering Properties of "A" Nickel*

Data from International Nickel Co., Inc. (Revised 1945)

WROUGHT NICKEL used throughout American industry is commercially pure metal, specifically "A" nickel to distinguish it from electrolytic nickel and from special alloys like "D" nickel containing 4.5% manganese and from "Z" nickel, an age-hardenable alloy containing 98.0% nickel. A carbon-free variety (carbon 0.02% max.) is known as "L" nickel to distinguish it from "A" nickel.

Nominal Composition of "A" Nickel*

	Wrought	Cast
Nickel (plus cobalt)	99.4	96.7
Copper	0.1	0.3
Iron	0.15	0.5
Manganese	0.2	0.5
Silicon	0.05	1.5
Carbon*	0.1	0.5

Magnetic Properties

Initial permeability, μ_o	110
Maximum permeability, μ_m	600
Saturation, gausses	6100
Hysteresis loss at saturation, ergs per cu.cm.	3000
Residual induction, gausses	3600
Coercive force, oersteds	3.4
Curie temperature, °C.	360

Endurance Limit and Apparent Corrosion Fatigue Limit of Monel, Nickel and Carbon Steels in Air, in Fresh Water and in Brackish Estuarine Water *(a)*

Material	Condition	Endurance Limit, Psi. for 10^8 Cycles	Apparent Corrosion-Fatigue Limit, Psi. for 10^8 Cycles	
			Fresh Water	Brackish Water
Nickel	Annealed	33,000	21-24,000	20-22,000
	Cold worked	50,000	21-24,000	20-22,000
Monel	Annealed	36,000	21-24,000	27-29,000
	Cold worked	50,000	21-24,000	27-29,000
Carbon steels		25-42,000	16-24,000	6- 8,000

(a) From "Corrosion Fatigue of Non-Ferrous Metals," by D. J. McAdam, Jr., *Proceedings*, American Society for Testing Materials, Vol. 27, 1927, p. 122.

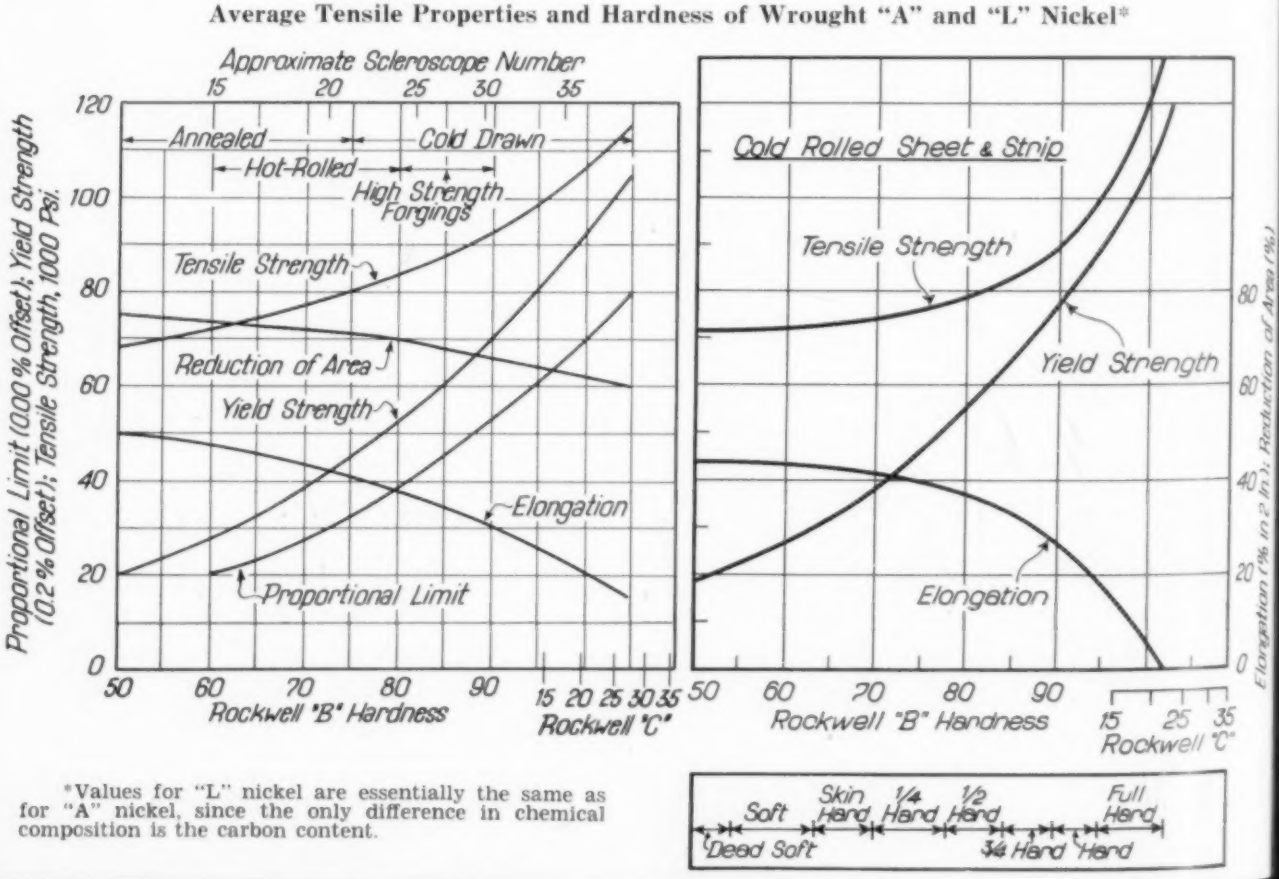
Physical Constants of "A" Nickel*

Specific gravity	8.89
Density, lb. per cu. in.	0.321
Melting range	
degrees Fahrenheit	2615 to 2635
degrees Centigrade	1435 to 1446
Specific heat at (80° to 212° F.) (27° to 100° C.)	0.110
Heat expansion coefficient	
at (80° to 212° F.), per ° F.	0.0000072
at (27° to 100° C.), per ° C.	0.000013
Thermal conductivity	
at (80° to 212° F.), Btu./sq.ft./hr./° F./in.	420
at (27° to 100° C.), cal./sq.cm./sec./° C./cm.	0.145
Electrical resistivity	
at 68° F., ohms/circ. mil. ft.	57
at 20° C., microhms/cm.³	9.5
Temperature coefficient of electrical resistivity	
per ° F.	0.0024 to 0.0028
per ° C.	0.0043 to 0.0050
Modulus of elasticity	
in tension, psi.	30,000,000
in torsion, psi.	11,000,000
Poisson's ratio	0.31

Short-Time High Temperature Tensile Properties

Test Temperature	Tensile Strength	Yield Strength (0.2% Offset)	Elongation in 2 In.
Room	24,000 psi.	73,000 psi.	49%
200° F.	21,000	77,000	52
300	21,000	76,000	46
400	23,000	79,000	49
500	24,000	76,000	48
600	22,000	83,000	50
700	22,000	80,000	50
800	21,000	76,000	52
900	20,000	65,000	51
1000	17,000	46,000	55
1200	15,000	34,000	57
1400	12,000	27,000	61
1600		16,000	76
1800		8,000	91

Average Tensile Properties and Hardness of Wrought "A" and "L" Nickel*



*Values for "L" nickel are essentially the same as for "A" nickel, since the only difference in chemical composition is the carbon content.

NE Steels for Bearings and Bolts in Farm Equipment

By J. H. Clark
J. D. Walker
and A. S. Jameson
Metallurgists★
International Harvester Co.

TOGETHER with the other industries the farm equipment manufacturers responded to the program for the conservation of essential alloys by inaugurating manufacturing research projects designed to further the substitution of steels with lower alloy contents, or to substitute a less critical alloy for a more critical one.

Due to the unavoidable uncertainty of the situation, as it developed in the early days of the war, with respect to the availability of alloys, one program would be started and another substituted before the completion of the first one. To illustrate, when the outlook became critical with respect to nickel, a change was made to chromium-molybdenum steels; chromium then became a critical alloy and this was shortly followed by a restriction of molybdenum, mainly caused by the swing from nickel-chromium steels to molybdenum containing steels.

The final and most logical solution to the problem of alloy conservation was the introduction of the National Emergency steels which utilized all the alloying elements commonly introduced into steel, such as silicon, manganese, nickel, chromium, and molybdenum. (Vanadium early became scarce because of its essential requirement as an alloy in toolsteels, as well as its use as a deoxidizer and grain refiner for steels of high importance to ordnance, and further because the change from high alloy content steels to low alloy steels posed primarily the question of hardenability and vanadium is not used as a promoter of hardenability.) In "hardenability" lay the key to the substitution of lower alloy content steels. Recognition of this fact gave considerable impetus to the study of hardenability with the outcome that steels will probably be purchased, in the future, on the basis of hardenability.

The present authors are competent to speak of the use of the NE steels only in the manufacture of farm equipment. The farm equipment "industry" covers a wide range of finished products, such as tractors, trucks, refrigerators, plows, harrows, corn pickers, mowers, combines. The production of each is in itself a special field. When these final products are broken down into individual parts, the range becomes so large as to preclude the possibility of discussing, in a single article, any but a few of the applications of NE steels.

It will be our effort therefore to describe a few specific parts which are of interest to metallurgists generally, because of their widespread use in many other industries. This first article will confine itself to the steels used in roller bearings and bolts; a subsequent article will present some pertinent information on properties of steels used in steering knuckles, axle drive shafts and (very briefly) transmission gears.

Roller Bearings

In certain sizes of conical roller bearings, such as shown in Fig. 1, and which comprise the largest tonnage used (estimated in 1942 to be about 200,000 net tons) S.A.E. 4620 (1¾% Ni, ¼% Mo) was the standard material. These bearings are used in tractors, trucks, and implements. In April 1941, due to the shortage of nickel, experiments were commenced using S.A.E.

★Of the authors, Mr. Clark is works metallurgist and Mr. Walker is metallurgist at the Fort Wayne Works of International Harvester, and Mr. Jameson is works metallurgist of its West Pullman Works in Chicago.

Fig. 1 — A Medium Sized Roller Bearing, Disassembled — an Item that Consumes About a Quarter-Million Tons of Fine Alloy Steel Yearly

4119 as a substitute. It contained no nickel, but higher manganese, ½% Cr and ¼% Mo. In May 1941, a special S.A.E. 4620 steel with a nickel content of 1.00 to 1.35% instead of 1.65 to 2.00% was used for bearing parts. Before the end of that month even steel of this nickel content became unavailable and A.I.S.I. A-4027 (Mn-Mo) was used, and in June 1941, a small quantity of S.A.E. 6120 (Cr-V). All these changes entailed a considerable amount of experimental work throughout 1941.

By February 1942, the Alloy Steel Section of the War Production Board set up a Bearing Sub-Committee of the Technical Advisory Committee, and experimentation proceeded with the newly proposed NE8720 or NE8620 and another steel (essentially an NE steel) known as R.B.E.C. 4720 of the following analysis: Carbon 0.17 to 0.22%, manganese 0.45 to 0.75, silicon 0.20 to 0.35, nickel 0.90 to 1.20, molybdenum 0.20 to 0.30, and chromium 0.25 to 0.50%.

An article by one of the present authors on the application of NE8720 to roller bearings was published in *Steel* for December 7, 1942. NE8720 has the following composition: Mn 0.70 to 0.90, Ni 0.40 to 0.70, Cr 0.40 to 0.60, and Mo 0.20 to 0.30. R.B.E.C. 4720 was finally adopted for these bearings and has been in use since June 1942. We will now compare briefly the properties of this steel with those of A.I.S.I. or S.A.E. 4620, the old standard.

Hardenability — As stated in the introduction, hardenability of a steel is one of the primary considerations when selecting a replacement. From known data we can assume that the lowering of the nickel content of A.I.S.I. 4620 steel from 1.65 to 2.00 to the new range of 0.90 to 1.20% in R.B.E.C. 4720 would lower its hardenability. However, this should be offset by the addition of chromium to the latter analysis.

The comparative hardenability of the two can be seen by comparing Fig. 2, and it will be seen that they have approximately the same hardenability values when end-quenched from 1650° F. — that is, the highest frequency for

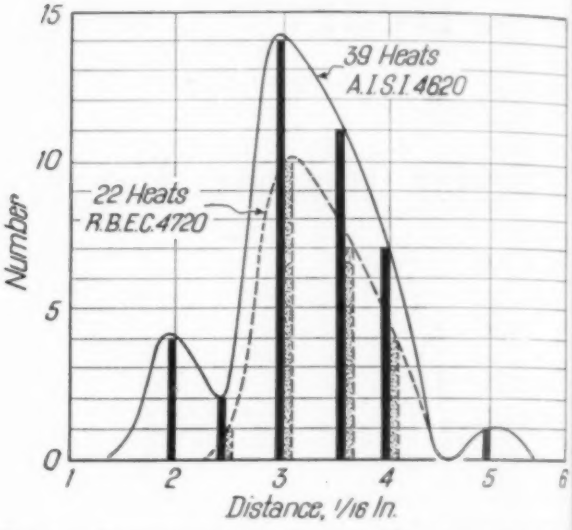


Fig. 2 — Frequency Distribution of Hardenability (Distance on End-Quenched Specimen to C-30) of Several Heats of A.I.S.I. 4620 and R.B.E.C. 4720. Samples normalized at 1650 and end-quenched from 1650° F.

C-30 for each class of steel is at 3/16 in. from the end, and the same general proportion of heats have equal hardnesses at 3 1/2/16 and 4/16. Four of the 39 A.I.S.I. 4620 heats had unusually shallow hardenability (2/16 in.); none of the R.B.E.C. 4720 heats were of this class.

(The standard end-quench test gives a curve showing hardness at different distances from the end, but it is very convenient to compare one steel or curve with another by noting the distance from the end to a certain hardness — in this case Rockwell C-30.)

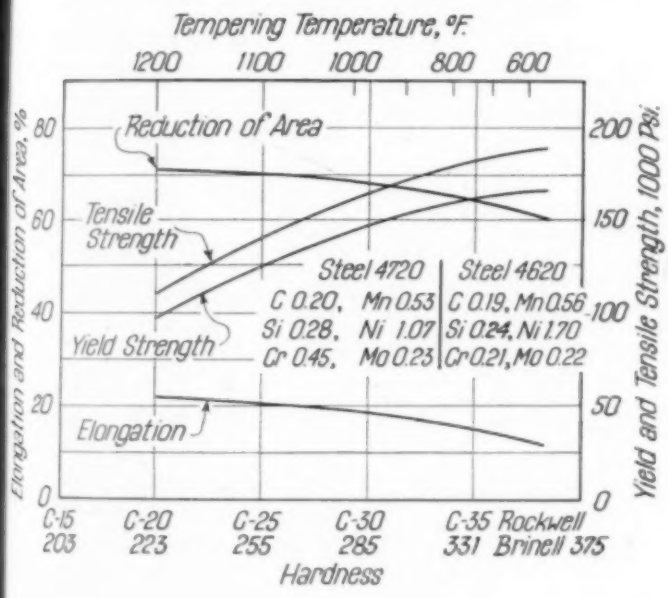
Tensile Properties — In comparing two steels of similar carbon content where the variant is the alloy content, it is customary to heat treat round sections of a diameter which will quench out to a uniform microstructure at least 50% martensitic, and determine the tensile properties from them. Although it is well established that all S.A.E. structural steels will have very similar tensile properties when the conditions noted above are met, there may be some differences in the ductility values (elongation and reduction of

area) for a given hardness or tensile strength. However one may define "toughness", certainly a steel which has higher reduction of area and elongation at a given hardness or tensile strength would be considered preferable.

As a matter of fact, tests made on the two steels as above outlined give results that agree within the experimental errors. Figure 3 gives these tensile properties of the steels after quenching from 1550° F. in water and tempering from 600 to 1200° F. at 100° intervals. Tests were made on 0.525-in. test bars (grain size No. 7 at 1700° F.) quenched in water from 1550° F. before tempering.

Carburizing — It would be expected that the response of 4720 to carburization would be, within practical limits, the same as 4620. A standard test, consisting of carburizing a

Fig. 3 — Average Tensile Properties of Roller Bearing Steels, 0.525-In. Bars Quenched From 1550° F. and Tempered to Various Hardnesses



1-in. round in a compound of known analysis limits for 8 hr. at 1700° F. and cooling slowly, was conducted on a representative heat of 4720. The carbon penetration curve obtained is compared with a range of curves obtained from many heats of the old standard 4620 steel in Fig. 4. It is seen that the carbon content of the case in this particular heat of R.B.E.C. 4720 is near the lower limit to be expected in A.I.S.I. 4620.

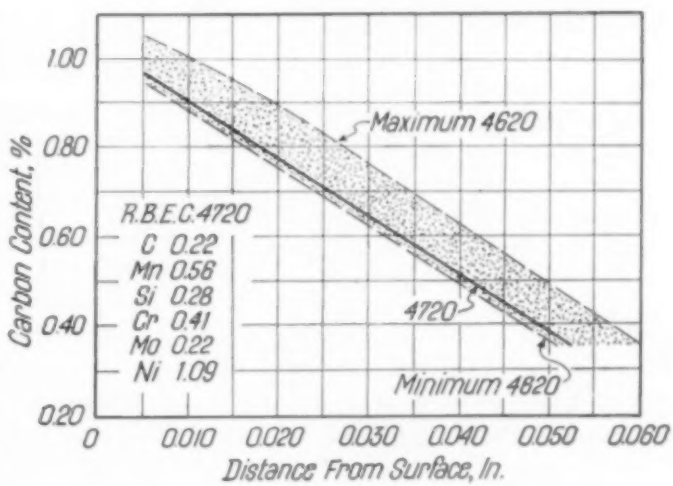
Fig. 4 — Carbon Penetration Curve for a Single Heat of R.B.E.C. 4720 (Austenitic Grain Size No. 7 at 1700° F.) as Compared to Expected Range for A.I.S.I. 4620. Samples carburized 8 hr. at 1700° F. and slowly cooled in coke-base carburizer containing 10% $BaCO_3$

Table I — Impact Tests on 4620 and 4720, Carburized

	A.I.S.I. 4620		R.B.E.C. 4720	
Hardness; Case	C-60 to 63		C-61 to 63	
Core	C-28 to 38		C-21 to 26	
Case depth	0.030 to 0.055 in.		0.044 to 0.053 in.	
Fracture grain size	8 to 9		8 to 9	
	Max.	Min.	Max.	Min.
Direct oil quench	28 ft-lb.	10 ft-lb.	21 ft-lb.	18 ft-lb.
Same; reheated, oil quenched from 1500° F.	43	13	23	21
Slow cooled, double quenched (1575 and 1500° F.)	37	15	25	20

Measuring to 0.35% carbon in carburized parts, a case depth of from 0.050 to 0.060 in. is to be expected, with a carbon content of not less than 0.90% and not more than 1.0% at a distance of 0.010 in. under the surface.

Toughness — Various non-standard tests are frequently used in examining carburizing steels, consisting of carburizing and hardening test pieces under certain conditions representing the heat treatment given finished parts to be made from the steel under study. We give preference to impact tests of hardened specimens, un-notched. However, comparative values may be obtained on grooved specimens, grooved with the object of localizing the fracture. This type of test is dependent on so many factors which influence the results that where comparisons between steels are made the specimens should be carburized, hardened, and prepared side by side. One of the main factors which affects the impact values is case depth, followed by grain size, and probably core hardness. But regardless of the extreme sensitivity of the impact values



to slight differences in test procedure, the impact or notched-bar test has proved to be of some worth in appraising the value of a steel in service.

Some values are given in Table I, for specimens carburized at 1700° F. in a 10% $BaCO_3$ compound, and treated as indicated, subsequently tempering at 325° F. in all cases. The hardness and other characteristics of the specimens are also shown.

It would appear from these tests that 4720 should be a satisfactory substitute for 4620.

There was, however, one disadvantage to 4720 in rings with heavier walls. It had a greater tendency to produce soft rings after the final hardening. This was true in spite of the fact that the hardenability as recorded on uncarburized specimens was the same. On the other hand, hardenability tests made on carburized specimens showed a higher hardenability for 4620 when hardened at 1480° F., which had been the customary hardening temperature for 4620 rings. These hardenability tests on carburized end-quench specimens are shown in Table II at the top of the page, where the criterion is the distance from the quenched end to Rockwell C-55. All specimens were carburized 8 hr. at 1700° F. in the standard carburizing medium, quenched in oil, reheated to 1480° F. and end-quenched by a water jet. Tests on 100 heats of A.I.S.I. 4620 and 50 heats of R.B.E.C. 4720 steel are summarized in Table II, above.

Table II — Frequency Distribution of Hardenability Tests on Carburized Steels

Distance to C-55 (1/16 In.)	100 Heats A.I.S.I. 4620	50 Heats R.B.E.C. 4720
5		1
5½		5
6		5
6½		11
7	4	7
7½		9
8	11	3
8½		2
9	11	1
9½		—
10	10	—
10½		3
11	13	3
12	10	
13	9	
14	8	
15	7	
16	4	
17	3	
18	7	
19	1	
20	1	
21	—	
22	1	

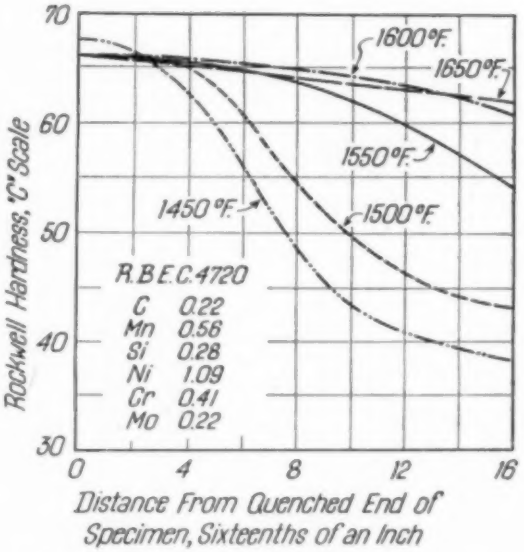


Fig. 5 — Effect of Quenching Temperature on the Hardenability of Carburized Jominy Specimens, R.B.E.C. 4720 Steel. Austenitic grain size No. 7 at 1700° F. Carburized in standard compound for 8 hr. at 1700° F.; oil quenched; reheated to temperatures as indicated and end-quenched by a water jet

We know, however, that an increase in the hardening temperature gives a marked increase in hardenability. This is shown graphically in Fig. 5. Knowing this, the hardening temperature of the race ring was increased to 1525° F., and no further difficulty was experienced.

The R.B.E.C. 4720 steel having been processed without any change in procedure except raising the hardening temperature, the final test as to the fitness of the steel is the accelerated life test. This consists of running assembled bearings under overload conditions to simulate their use in service. Of course, accelerating failure by overloading is not quite the same thing as service operation but it does give some indication of their field performance.

Numerous accelerated life tests made under parallel conditions showed that bearings made from 4720 were comparable with bearings made from the old standard 4620 steel.

Application of NE Steels to Bolts

S.A.E. 3135 and 4130 (or 4135) were popularly used for bolts up to about 1¼ in. diameter. (See Fig. 6.) At about the time of the anxiety regarding the country's alloy stocks there was a wide use of 4042 (C-Mo) steel, but it had some hardenability limitations in bolt sizes over ⅝ in. so that some 3135 and 4135 was still used. When 4042 became impossible to obtain because there was little or no alloy-free scrap from which to make it, one of the earlier NE alloy steels (8339) was experimented with. Its use was later abandoned because of the undesirability of its alloy combination in steel-mak-

ing routine, namely, manganese and molybdenum.

A little 1335 (1¾% Mn) was also used. It did not become too popular because, generally speaking, manganese over 1.60% is not particularly desirable for cold working. Because of its association with the ferrite constituent, manganese causes rapid work hardening of the ferrite, and where several cold working operations are involved it becomes necessary for safety's sake to anneal between operations. For a time, preference was given to NE9437 (Mn 1.0%, Ni 0.45%, Cr 0.40%, Mo 0.10%) and it was extensively used for two years. However because of its lower manganese content and lower cost NE8637 is now replacing NE9437.

Fig. 6 — Typical Bolts Used by the Farm Equipment Industry

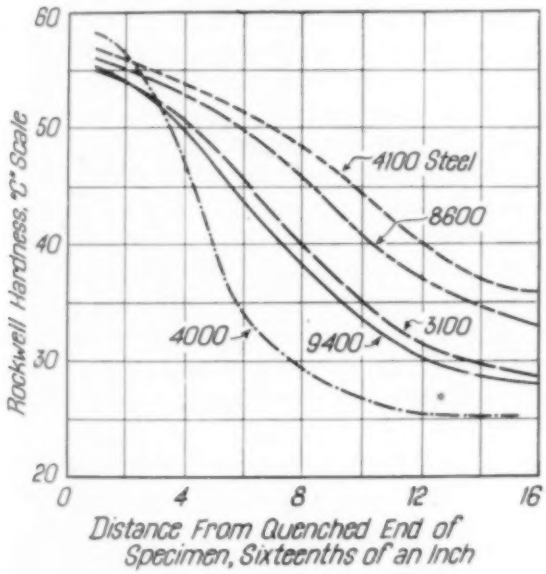
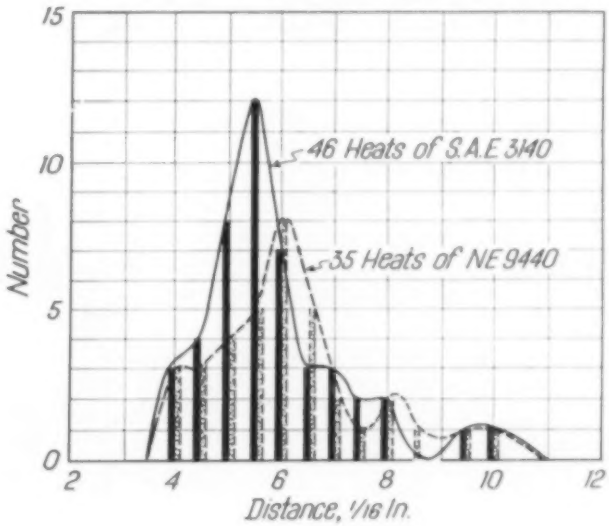


Fig. 7 — Approximate Hardenability of 3100 (Ni-Cr), 4000 (C-Mo), 4100 (Cr-Mo), 8600 (Low Ni-Cr-Mo) and 9400 (Mn-Ni-Cr-Mo) Steels in 0.33 to 0.43% Carbons. All samples normalized at 1650° F., heated to 1550° F. for 35 min., and end-quenched by water jet

Fig. 8 — Frequency Distribution of Hardenability (Distance to C-45) of S.A.E. 3140 and NE 9440 Steels. All samples treated as in Fig. 7



As in the other substitutions of NE alloy steels for the old standard S.A.E. or A.I.S.I. alloy steels, the hardenability of bolt steel is an important consideration. The comparative hardenability of 3100, 4000, 4100, 8600, and 9400 steels in carbon ranges from 0.33 to 0.43% is approximately as shown in Fig. 7. The term "approximately" is used because there is naturally a considerable spread in hardenability within each steel analysis. By looking at Fig. 8, which contains frequency distributions for several heats of 9440 and 3140, this will become apparent. It also shows that the NE9440 heats are slightly, but only slightly, more hardenable.

Commencing with the premise that in order to obtain maximum tensile properties from a bolt the section must be hardened throughout by oil quenching to produce at least a 50% martensitic structure before tempering, the tensile test would be the usual means of evaluating a bolt. On this

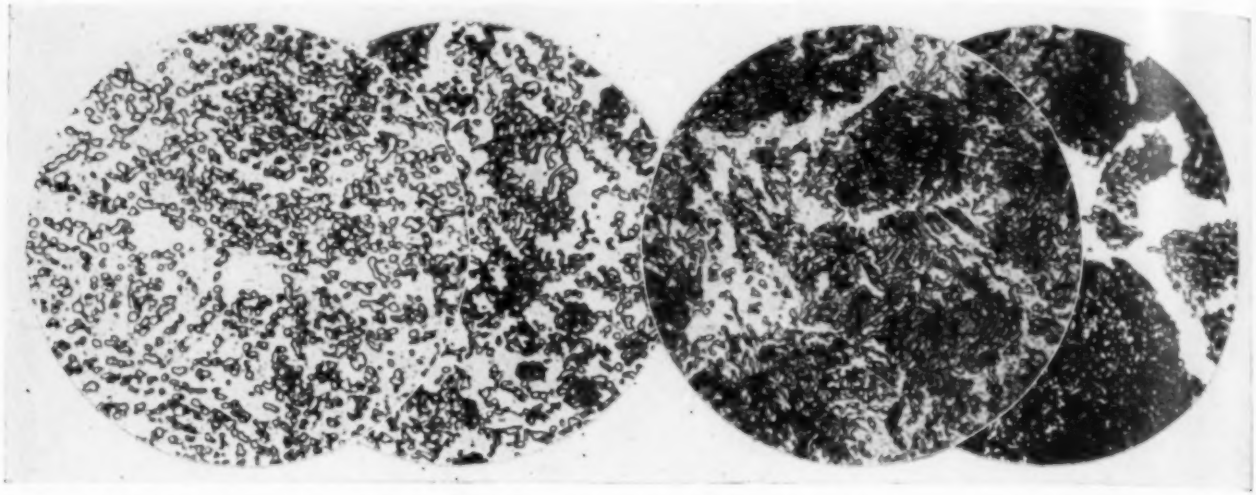


Fig. 9 — Acceptable Spheroidized Microstructure of NE 9400 Steel Wire or Rod for the Manufacture of Cold Headed Bolts, as Contrasted With Unacceptable Pearlitic Structure (Right)

basis of hardenability, the suitability of each type of steel may be determined by calculations from the curves of Fig. 7. This is done by correlating the cooling rates at various locations along the Jominy end-quenched bar with the cooling rates at surface, half-radius and center of round bars during quenching in still oil.* Such correlations are given in Table III. (In this table the "hardenability rating" or "J-value" is the distance along the end-quenched bar to the specified hardness, either C-50 or C-45. The hardness of a medium alloy steel with 0.40% carbon, quenched to 50% martensite, is at most C-45.)

Assuming that center hardness of C-45 after oil quenching is the main consideration, because of its relation to tensile properties, it will be seen that 9400 and 8600 steels would be, from the hardenability standpoint, satisfactory substitutes for all bolts up to at least ⅞ in. diameter.

Of course, the approval of a new material would not be given on the basis of a hardenability test alone. Bolts would be made up from the new steel, observing the manner in which it headed and heat treated in the established practice. Also, a series of tensile tests would be made on the finished parts. The data so obtained would be compared with that already existing for the old material and from this the suitability of the new material would be decided.

In cold heading practice the 9400 steel, when used to replace the 4000 steel, gave some difficulty, mainly when trimming hexagon head bolts.

*A graphical method of doing this is described by B. F. Shepherd in *Metal Progress* for March 1944, page 503.

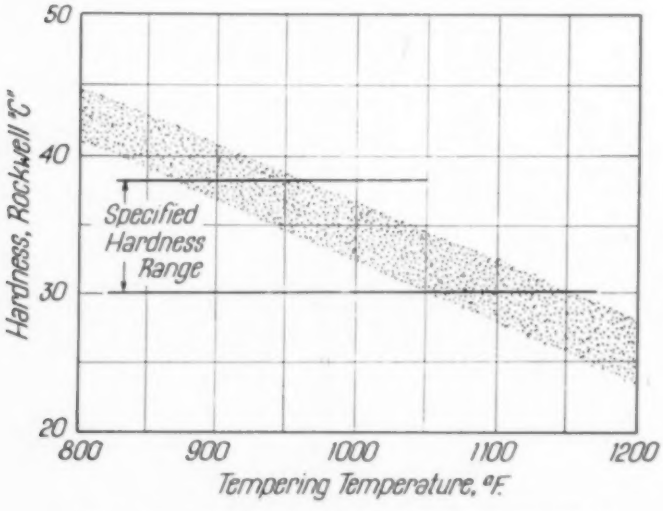


Fig. 10 — Hardness of NE 9437 Bolts in Various Sizes (⅜ to ¾ In. Diameter) Oil Quenched From 1550° F. and Tempered as Shown

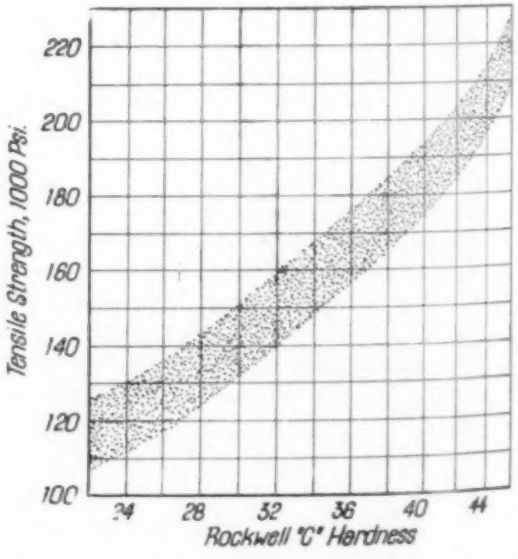


Fig. 11 — Relationship of Hardness to Tensile Strength of NE 9437 Bolts in ⅜ to ¾-In. Size

Trimming die life appreciably decreased and the bolts tended to split in the head. In order to run in a trouble-free manner considerable attention had to be paid to the microstructural condition of the bolt wire; an almost completely spheroidized structure was found to be desirable, as shown in Fig. 9.

In heat treating, NE9400 and 8600 bolts responded equally as well as the other alloy steels previously used. The bolts made from these new materials are hardened in oil from 1550° F. and tempered at 1000° F. The data in Fig. 10, obtained from 10 heats and representing the hardness of 900 pieces, show that a hardness specification of C-30 to 38 can be met with a tempering temperature of from 925 to 1075° F., with 1000° F. as a mean.

Assuming that the bolts are hardened throughout, a prediction as to the tensile properties can be made, for hardness is intimately related to tensile strength. Figure 11 gives the relationship between hardness and tensile strength for NE9437 bolts in sizes from ⅜ to ¾ in., determined from 1080 tests on 12 heats of steel. It would be expected that all bolts made from this steel or any other similar low alloy steel would, at a given hardness, fall within this band.

One other important requirement of a bolting steel is that it be tough enough to "give" somewhat without breaking. This property is estimated from the elongation and reduction of area values for a given tensile strength. It is true that within certain limits all S.A.E. constructional alloy steels exhibit comparable "toughness" values for a given tensile strength, estimated in this way. However, there are differences between the various alloy types, and it would be advisable to study these differences when considering the adoption of another analysis. The determination of these values is difficult on a finished bolt, and it is probably better to find the relationship between tensile strength and reduction of area on standard test bars, preferably on heats with carbon contents within a 5-point range — since, theoretically, the higher the carbon content

Table III — Maximum Diameters of Bars Which Will Oil-Quench to Given Hardness at Places Indicated
(Carbons in each type: 0.33 to 0.43%)

	3100	4000	4100	8600	9400
	Hardness: C-50				
J-value (1/16 in.)	4	3.5	7	6	4
Surface	1.8 in.	1.6 in.	2.7 in.	2.4 in.	1.8 in.
¾ radius	1.0	0.9	1.8	1.5	1.0
½ radius	0.8	0.7	1.4	1.2	0.8
Center of bar	0.6	0.5	1.2	1.0	0.6
	Hardness: C-45				
J-value (1/16 in.)	6	4.5	9.5	8.5	6
Surface	2.4	2.0	3.3	3.1	2.4
¾ radius	1.5	1.2	2.3	2.1	1.5
½ radius	1.2	0.9	1.9	1.7	1.2
Center of bar	1.0	0.7	1.7	1.5	1.0

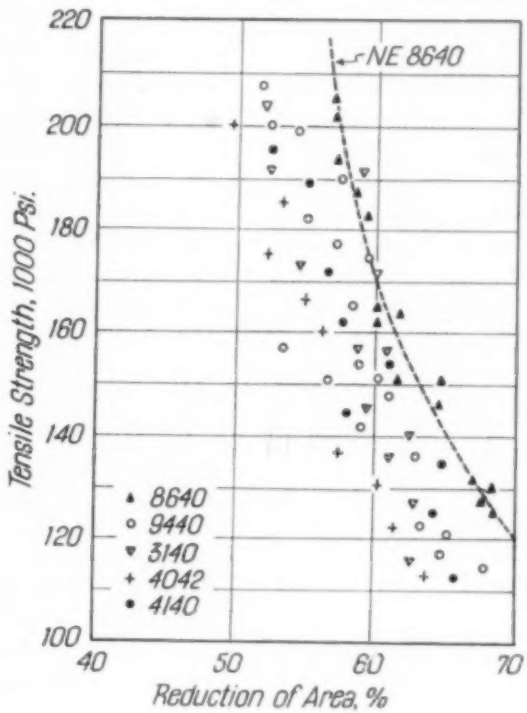


Fig. 12 — Relationship Between Tensile Strength and Reduction of Area of 0.500-In. A.S.T.M. Test Bars, Quenched and Tempered. Three or four heats in each analysis are involved

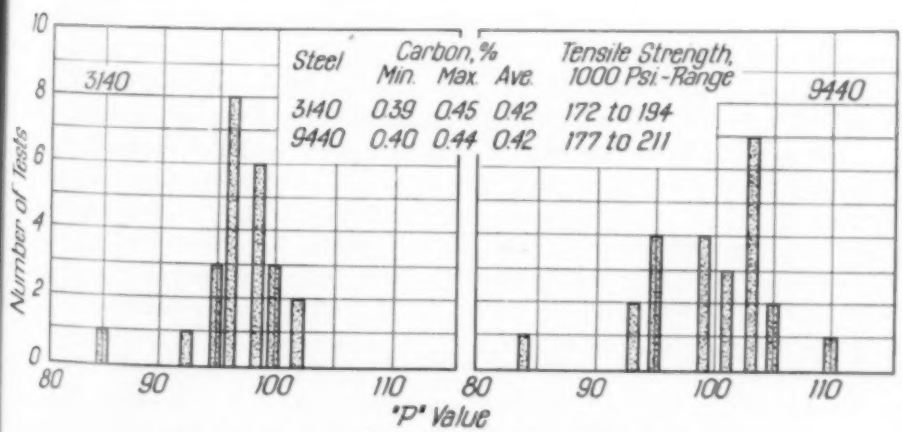


Fig. 13 — Schenck's "P" Value for Tests From 25 Heats of S.A.E. 3140 and 25 Heats of NE 9440.

$$P = \frac{\text{Tensile Strength (Psi.)}}{5000} + \frac{6}{5}\ \text{Reduction in Area in \%}$$

of the steel the lower will be the toughness at a given tensile strength.

Figure 12 gives some comparative data on 3140, 4040, 4140, 8640, and 9440 steels. Three to four heats of each analysis are involved. From these data it could be concluded that NE8640 has a higher reduction of area for a given tensile strength and, therefore, is to be preferred over the other steels shown. However, caution should be exercised in drawing final conclusions from tests on a relatively few heats of steel.

It would be more in line with the truth to conclude that NE8640 is as desirable as any of the other steels, for unless a statistical analysis is made of sufficient data covering, say, 100 heats of steel — or at least considerably more than three or four — any conclusion arrived at other than this general statement, would be extremely rash, to say the least.

To illustrate, a study was made of 25 heats of S.A.E. 3140 and the same number of heats of NE9440 steel. The results are shown in Fig. 13. The relationship is shown as the "P" merit value, recommended by R. B. Schenck of Buick Motor Co. The P value is computed by dividing the ultimate tensile strength, expressed in 1000 psi., by 5, and adding 6/5 of the reduction of area, expressed in per cent. All test bars (0.500-in. A.S.T.M.) were oil quenched from 1550° F. and tempered at 900° F. Figure 13 shows NE9440 to be superior to S.A.E. 3140 steel, in that the P values are, on the whole, considerably higher. However, caution is warranted even with tests on 25 heats. It may be noted, for example, that a curved line joining the peaks of the vertical bars in Fig. 13 for S.A.E. 3140 would trace out a smooth curve, approximating the shape of the probability curve. On the other hand, such a curve for the NE9440 heats plotted in Fig. 13 would show marked irregularities. This might well be interpreted as meaning that — whereas the tests on S.A.E. 3140 represent steel mill production under close control — the NE9440 heats are affected by unknown manufacturing variables and the values for 25 heats may not be truly representative of continuous production. It would therefore be safer to conclude that 9440 and 3140 are comparable as far as toughness at a given hardness is concerned.

However, judging from observation of 9440 in production and the performance of bolts made from this material in service, this NE steel is an adequate substitute for any of the old 3140, 4040, or 4140 steels.

Correspondence

Pipe Lines to France

LONDON, ENGLAND

To the Readers of METAL PROGRESS:

Pipe lines for water and petrol ("gasoline" to Americans) played a large part in all the British Army's operations in North Africa, as could well be expected from the barren nature of most of the terrain. Equally well known are the large petroleum lines laid across the United States to carry crude oil to the Eastern refineries, and the network of lines laid in England to transport petrol from ocean ports to the many airfields and camps where motorized equipment was centered.

Only recently has news been released about "Operation Pluto", the laying of no less than 20 pipe lines under the English Channel. Between D-day and VE-day about 120 million gallons of gasoline have been pumped to Boulogne or Cherbourg, and thence by ever lengthening pipe lines to the eastward-moving British and American armies.

Original experiments were made with a line something like a submarine electric power cable without cores and insulation. This work was suggested by the undersigned who, as chief engineer of the Anglo-Iranian Oil Co., had used 3-in. high-pressure pipe lines in Persia. This 3-in. inside diameter lead pipe appeared to answer the purpose. Subsequently, they were strengthened for pressures up to 3500 psi. by four layers of steel armoring strips (cold rolled, mild steel strip, with 45,000-psi. min. yield) and a cover of 57 galvanized steel wires with 60,000 psi. tensile strength. To protect this from sea water and handling damage, final covers of jute, asphalt and whiting were applied. Two 30-mile lengths of such cable were furnished in record time from American

firms, so that full-scale trials could be held in Bristol Channel, where the currents and other conditions approximated most closely those found in the English Channel, and it was successfully laid when half-a-gale was blowing. The fact that the cable was large and hollow increased the difficulties, since it was liable to kink and so stop the oil flow. The cables were therefore full of water at 30-lb. pressure while being manufactured and under 200-psi. pressure while laying, which kept them safely inflated. This variety of pipe was called the HAIS (Hartley-Anglo-Iranian-Siemens).

Meanwhile another pipe was invented by B. J. Ellis, chief oilfields engineer of the Burma Oil Co., and H. A. Hammick, chief engineer of the Iraq Petroleum Co. This second pipe, named "Hamel", was composed of 20-ft. lengths of 3-in. diameter steel pipe, ¼-in. wall, flash welded automatically end to end and wound on a drum like thread on a spool. This floating drum was capable of carrying the full length of pipe required for the Channel crossing, and during the sub-marine laying operation the drum was towed by tugs like a large bobbin, paying off the pipe as it went.

Within a few months, a special factory in the Thames Estuary was equipped for welding 20-ft. lengths of the Hamel pipe into 4000-ft. lengths at a rate of 10 miles daily, with facilities for storing the lengths to a total of 350 miles. Shortly afterwards a duplicate factory was established to provide against the possibility that the first should be bombed.

The floating drums, 40 ft. dia. by 60 ft. long, were moored in deep water at the end of the pipe-racks, so the 4000-ft. lengths might be welded into a continuous length of 30 or more miles, and wound on the 40-ft. drums. When fully wound a drum weighs 1600 tons — the weight of a destroyer — and carries 70 miles of pipe line.

New pipe lines were run on land from the British network system to take the gasoline to the coast, and the special high pressure pumping stations at the shore line were cleverly camouflaged. Pipe laying began as soon as enemy mines had been swept from the approaches to Cherbourg Peninsula. The lines running from the Isle of Wight to Cherbourg took 10 hr. to lay and conveyed gasoline to the United States armies. The cross-channel lines established as soon as Boulogne was captured took five hours to lay and transported gasoline to the British 21st Army Group.

A. C. Hartley
Technical Director
Petroleum Welfare Dept. of Great Britain

Correction for Nomograph for Calculation of Corrosion Rates

Wilson Dam, Ala.

To the Readers of Metal Progress:

The Nomograph for Calculation of Corrosion Rates, which appeared on page 1059 of the December 1942 issue, and on page 914 of the October 1944 issue of *Metal Progress*, as well as page 49 in the collected group of data sheets published loose leaf by the ASM, contains an error in the graduation of Axis B (representing the corrosion rate in g. per sq.dm. per day). This error does not affect the results obtained when calculating corrosion rates in inches penetration per year, because Axis B is then used only as a reference line.

Correct graduations may be placed on Axis B in the following manner: Draw a line from 0.001 g. per sq.in. on Axis A to 16 days on Axis C. The point of intersection of this line with Axis B corresponds to a corrosion rate of 0.001 g. per sq.dm. per day, and may be used as the origin of a five-cycle logarithmic scale on Axis B. The length of each cycle can be obtained as follows: Draw a line from 0.002 g. per sq.in. on Axis A to 3 days on Axis C. The point of intersection of this line with Axis B corresponds to a corrosion rate of 0.01 g. per sq.dm. per day. The distance between these two points, located as 0.001 and 0.01 g. per sq.dm. respectively on Axis B, is the length of each logarithmic cycle on the new scale. To cover fully the useful range, five equivalent logarithmic cycles should be constructed on Axis B to cover a range from 0.001 to 100 g. per sq.dm. per day.

E. P. Tait
Process Development Division
Tennessee Valley Authority

Stress Corrosion of 4% Copper-Aluminum Alloy

New Kensington, Pa.

To the Readers of Metal Progress:

The January 1945 issue of *Metal Progress* contains a summary of the symposium on stress corrosion cracking held last November, a clear presentation of this rather involved subject. We note, however, on page 77 in the section captioned "Electrochemical Nature of Stress Corrosion Cracking", data from one of our papers have been misinterpreted. The summary states, "... the potential differences between the grains and the grain boundaries of a quenched aluminum alloy containing 4% of copper were observed

over a period of time in a solution of sodium chloride in hydrogen peroxide." This, and the sentence immediately following it, suggests that we measured the variation in potentials of the specimens as a function of their time of exposure to the test solution. This is not the case. We measured the potentials of the grains and grain boundaries of specimens which had been artificially aged at an elevated temperature (375° F.) for various periods of time. The data are given in Fig. 2 of Preprint No. 20 by Messrs. Mears, Brown, and Dix. In this figure, the time axis is clearly marked "Aging Time — Hours at 375° F."

Also, we do not believe there is any justification for the summarizer's statement in the last sentence in this same section: "They did not consider the possibility that the difference in potential between the grains and their boundaries may be directly influenced by stress." It is true that in the paper we did not mention this possibility, but we had considered it and had made special tests with both brass and aluminum alloy specimens which indicated that stress has a negligible effect on solution potential, under our conditions of test.

ROBERT B. MEARS
Chief, Chemical Metallurgy Division
Aluminum Research Laboratories
Aluminum Co. of America

Specifications for Electrodes

CLEVELAND

To the Readers of METAL PROGRESS:

Industry in general, and the welding industry in particular, has been greatly handicapped by the lack of a real technical standard covering electrodes. True it is, there has been in existence for some years a so-called standard which actually might be termed a "buyers' guide" known as American Welding Society's "Tentative Specifications for Iron and Steel Arc Welding Electrodes". However, this contains so many discrepancies with ambiguous statements that it is unsatisfactory. Let me cite a few examples:

> Tests are required on all sizes of $\frac{5}{32}$ in. and above, but none are required on $\frac{1}{8}$ in. and smaller, so why have tests on *each* larger size?
>
> A manufacturer cannot use the same electrode for two or more classifications; this in spite of the fact that the ideal electrode, of course, is one which would fulfill all classifications.
>
> "The coating shall not have scabs, blisters, abnormal pockmarks, bruises, or other surface defects that shall be injurious." (Just what is injurious?)

These are only a few of the idiosyncrasies of this "buyers' guide". Therefore, it can readily be seen that what is needed is a simple, easily understandable standard. Since there is no need for a weld stronger or better than the material to be welded, I suggest for mild steel — which covers 90% of the requirements — a simple standard, something as follows:

> The electrode shall be of such characteristics that it will withstand the following tests to be made any time a buyer might desire: *(a)* A weld made in $\frac{3}{8}$ or $\frac{1}{2}$-in. plate of mild steel, planed to the same thickness as the parent metal, must break outside of the weld when pulled in a standard tension machine. *(b)* On a section from the same plate mentioned in *(a)*, welds may be bent in any way desired and elongation of 25% in the outside fibers must show no fracture.

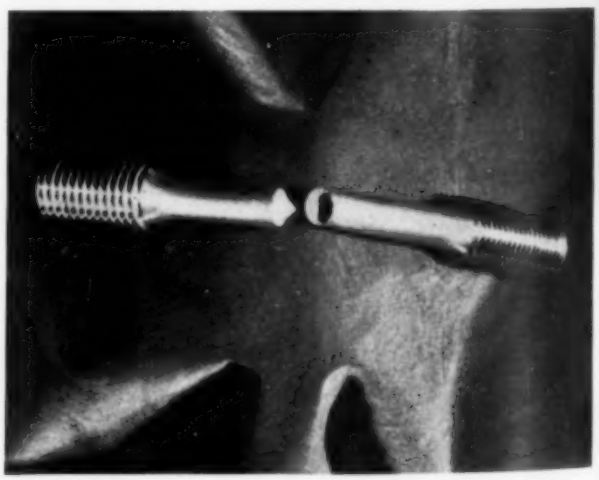
An electrode which will perform as indicated in these two tests will give a weld equal in physical qualities to the plate. With such a weld, porosity is of no consequence. However, a simple test could be made as follows:

> A fracture shall be made through the weld. On a straight line through the fractured weld there shall be voids of no more than 5% cumulatively.

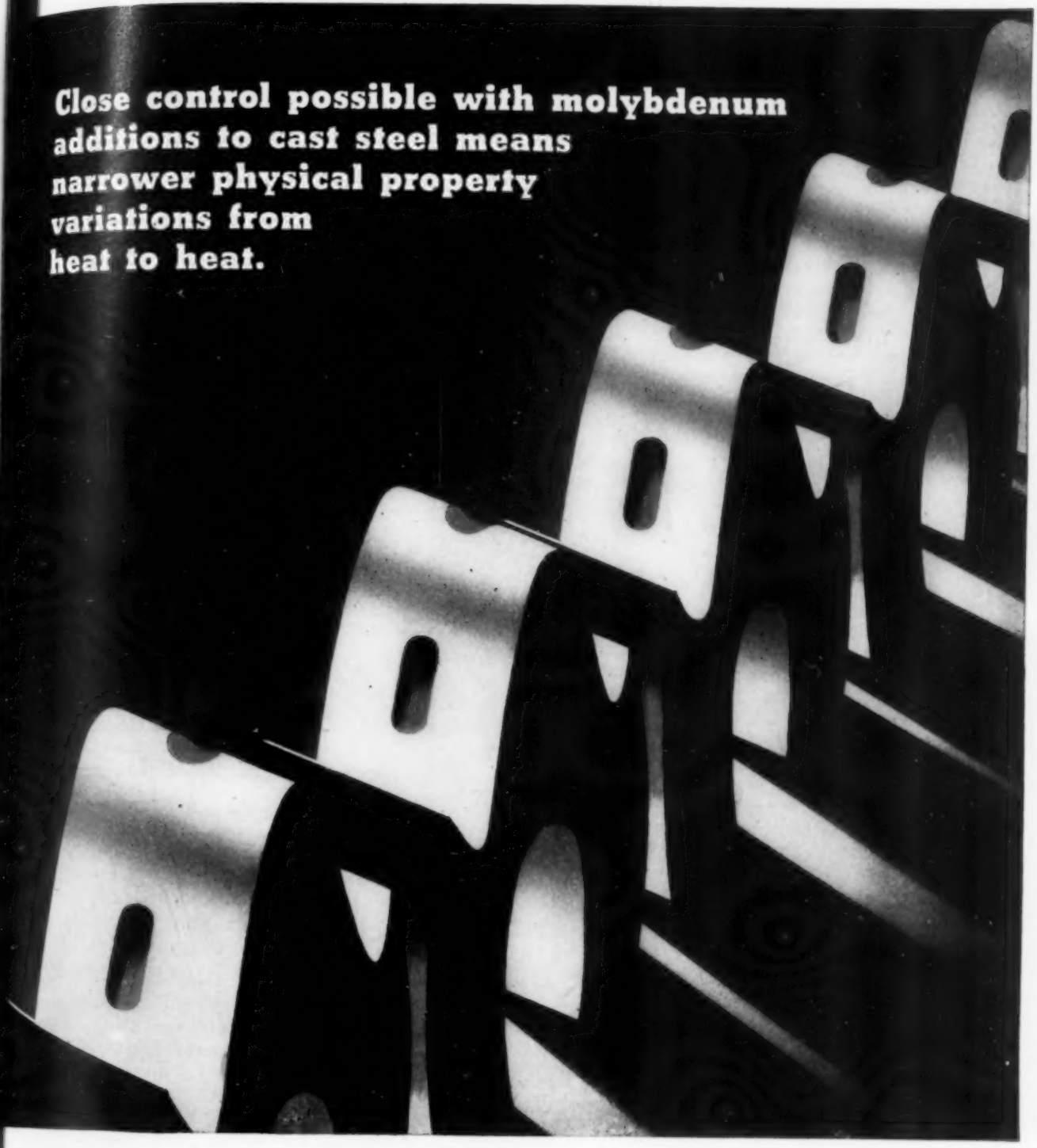
An electrode which will withstand the above very simple tests will be satisfactory in welding mild steel, so why complicate matters? It seems to me that this is a question to which the American Welding Society's committee, and the associated group of the American Society for Testing Materials, should give proper attention.

J. F. LINCOLN
President
The Lincoln Electric Co.

Perfect Cup-Cone Break



"As Perfect a Cup-Cone Break as We Have Ever Seen", Writes W. W. Edens, Metallurgist of Ampco Metal, Inc., of Milwaukee. Metal: Aluminum bronze (8.5% Al, 2.8% Fe), as cast, 81,000 psi. ultimate; 48% elongation in 2 in.



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Personals

GERARD H. BOSS, formerly plant metallurgist, Reynolds Metals Co., Louisville, Ky., is now senior metallurgist, Baldwin Locomotive Works, Eddystone, Pa.

FRANCIS A. BOULANGER has been assigned to Lonergan Co., Albion, Mich., as resident chemical warfare inspector in charge.

OWEN W. ELLIS, director of the engineering and metallurgical department of the Ontario Research Foundation, has been elected chairman of the metallurgy division of the Canadian Institute of Mining and Metallurgy.

Promoted by Joseph T. Ryerson & Son, Inc.: WEAVER E. FALBERG, from assistant manager of special steels at Cincinnati to manager of the special steels department at the Cleveland plant.

H. P. CROFT has been relea from active duty as lieuten colonel, chief of the industrial di sion, Cleveland Ordnance Distri and has returned to Chase Br and Copper Co. as director of te nical control and research, m western division, Cleveland.

CHARLES M. WHITE, vice-pre dent in charge of operations Republic Steel Corp., has been m president of the company, succe ing R. J. WYSOR, who is supervis the Allied Control Council's me lurgical operations in Germany.

J. D. ZAISER has been elec executive vice-president and g eral manager of Ampco Metal, I Milwaukee.

WALTER H. BRAUN, forme with Halcomb Works of Cruci Steel Co. of America, is now me lurgist for Eastern Stainless St Corp., Baltimore, Md.

DAVID M. GANS, formerly sistant director of research, cent research laboratories, Interche ical Corp., has been appointed te nical director for Quaker Chemi Products Corp., supervising the search, service and control labo tories in Conshohocken, Pa.

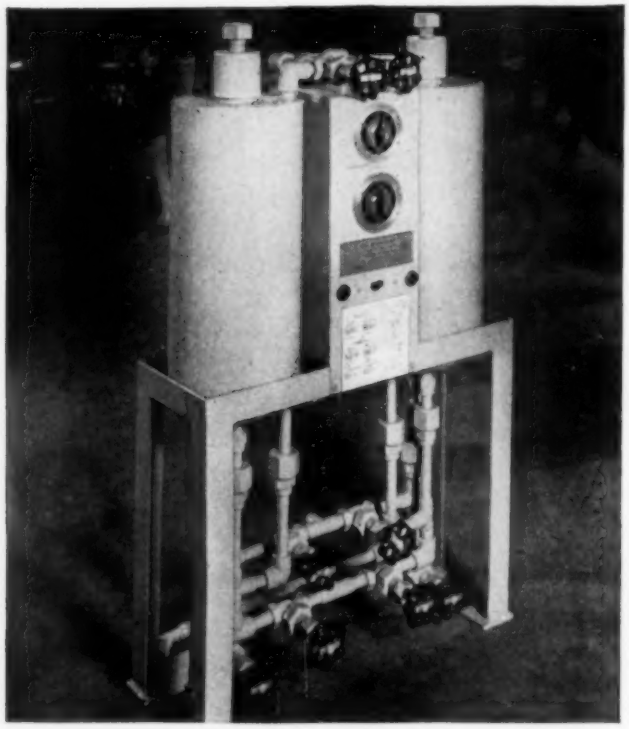
MILES K. SMITH, metallurgi engineer, has become associat with WILLIAM H. PHILLIPS, vi president, and NORMAN F. TISD, chief metallurgist, in the Pi burgh office of the Molybden Corp. of America, in the capac of sales and service engineer.

D. W. BAUGHMAN is now e ployed on the metallurgical staff Aluminum Co. of America's Laf ette plant of the fabricating divisi

EDWARD C. SLICK, forme with the metallurgical research partment of the Sylvania Electr Products, Inc., at Bayside, L Island, N. Y., has been appoint senior metallurgical engineer the weld and wire products di sion of the company at Warren, P

A. GLIBKOWSKI has resign from the Studebaker Aviation Co to become chief chemist with t Hollup Corp., Chicago.

OTTO K. KORTH, formerly wi Tubular Micrometer Co., has cepted a position in the engineeri department of Minnesota Mining Mfg. Co., St. Paul, Minn.



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Personals

S. LEROY CRAWSHAW has been appointed manager of engineering and sales, Western Gear Works, Lynwood, Calif. W. A. WITHAM has been appointed assistant manager of engineering, and P. L. BANNAN, company treasurer, has been appointed manager of manufacturing for all plants, with G. A. DEARMAND as his assistant.

Promoted by Carnegie-Illinois Steel Corp.: JOHN MITCHELL, to manager of the products section of the alloy sales division. ALBERT L. KAYE, formerly manager of the alloy bureau, Chicago metallurgical division, succeeds Mr. Mitchell as metallurgical engineer, alloy steel products, in Pittsburgh, and MAURICE J. DAY, formerly alloy contact representative servicing automotive manufacturers, succeeds Mr. Kaye as manager of the Chicago alloy bureau.

A. B. GRENINGER, who for the past two years has been doing special war work in Chicago, has been appointed metallurgist of the chemical department of General Electric Co. in Pittsfield, Mass.

JOHN W. LOHNES, formerly assistant general manager of sales, Vanadium Corp. of America, has been appointed district sales manager, Chicago district, succeeding the late LEROY F. JOHNSON.

J. ROBERT VAN PELT, formerly technical director, the Museum of Science and Industry, Chicago, has been appointed to the staff of Battelle Memorial Institute, Columbus, to take charge of an expanded program of research education.

DUDLEY E. CHAMBERS has been promoted to executive engineer of the General Electric Research Laboratory, Schenectady, N. Y.

FRED STIRBL is now research metallurgist with the Crucible Steel Co. of America, Harrison, N. J.

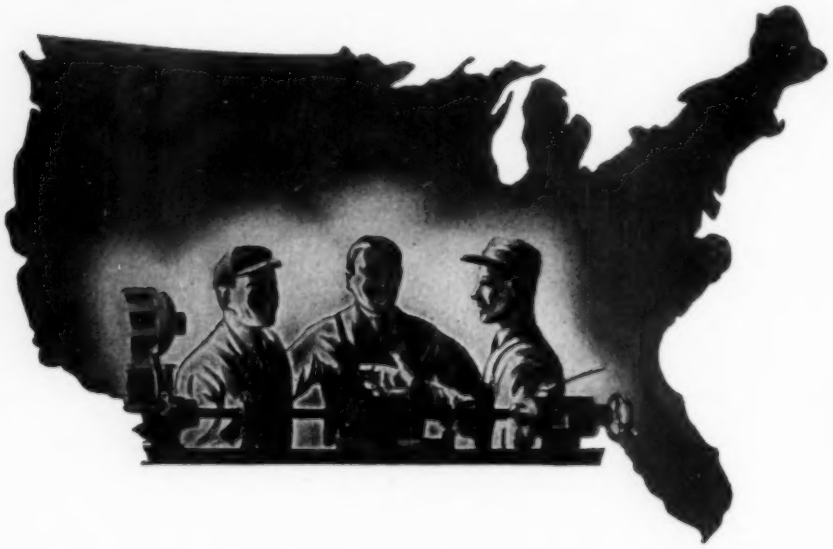
JOHN H. FROME, JR., formerly with Jacobs Aircraft Engine Co., is now employed as metallographer by W. B. Coleman & Co., Philadelphia.

RALPH V. HILKERT has resigned as metallurgist for South Works of Carnegie-Illinois Steel Corp., Chicago, to assume the position of research metallurgist for Solar Aircraft Co., San Diego, Calif.

EARL W. PIERCE, formerly assistant to general superintendent, South Chicago plant of Carnegie-Illinois Steel Corp., has been appointed chief metallurgist. TOM J. PETERS, formerly assistant superintendent of the maintenance division, succeeds Mr. Pierce as assistant to general superintendent.

W. SPRAGEN, executive secretary of the Welding Research Council of the Engineering Foundation, and editor of the *Welding Journal*, has been appointed to the newly created position of director of the Welding Research Council.

CHILDRESS B. GWYN, JR., formerly chief engineer and general manager, Chicago division, Allied Control Co., Inc., is now chief engineer and general manager, tungsten and sintered metals division, the H. A. Wilson Co., Newark, N. J.



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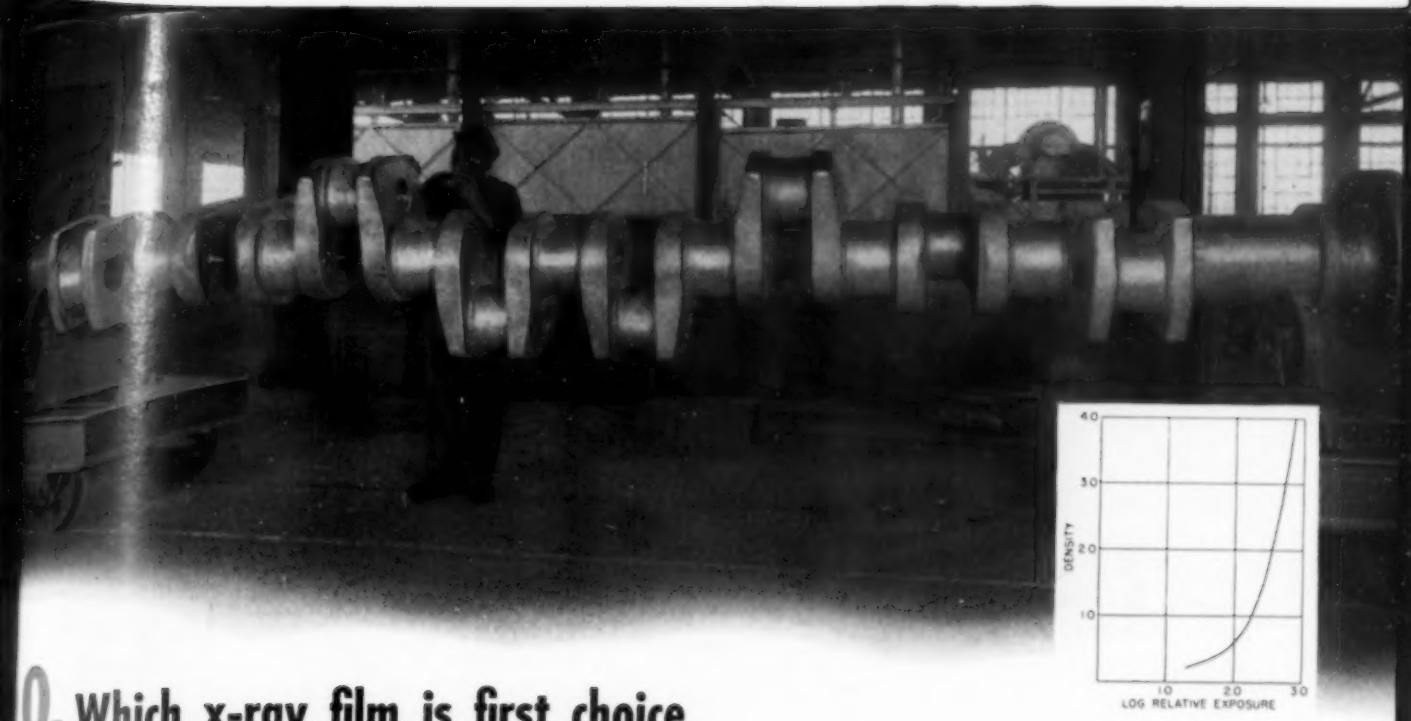

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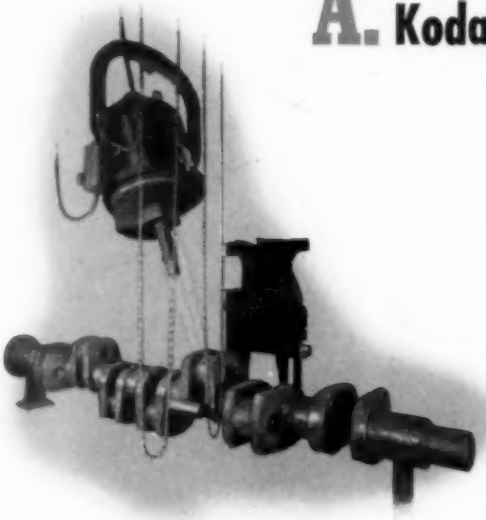
A. Kodak's Type M



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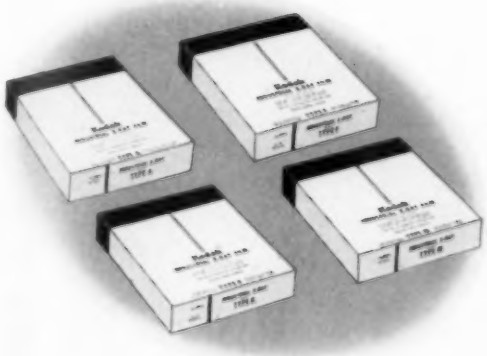

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Gun Tubes

(Continued from page 72)

Physical Tests — The physical properties required to make a high quality gun tube are a high yield strength, and a high reduction of area in the transverse direction. A high impact value is also required in some highly stressed guns. In order to meet these high physical properties, it is essential that a completely martensitic structure be developed in the heat treatment and quench, and that the final structure after tempering contain little or no free ferrite.

Some metallurgists have supposed that the impact (notched-bar) strength is a measure of the thoroughness of the quench — that is, whether or not the quenched structure is fully martensitic. It has also been supposed that the reduction of area transverse is a measure of the steel quality — for dirty steel seldom has a good "R.A.(t.)" value. Finally, that the yield strength is a measure of the tempering operation.

Probably one reason for the very excellent physical results attained with 4337 steel employed in seamless gun tubes was that the quench was very thorough. This was possible because the mass of the quenching medium was large with relation to the mass being quenched, and because the tubes had a hole through them and a large quantity of water could be forced up through the tube at the same time it was being cooled externally. The quench was from both outside and inside and was very effective.

Precise quenching temperatures need not be given, but it is important to remember that the temperature of the quenching water was controlled simultaneously, as was also the time of quench. Very little trouble was experienced with quench cracks except when the tubes had not been normalized. If the physical tests were lower than specified the gun tube would be re-heat treated and retested. (Tubes were long enough so two test disks could be cut from each end.)

At first, tests were pulled from disks cut from the muzzle and breech end of each gun tube, but as time went on and the physical results were so uniformly good, the Ordnance Dept. established a new quality control specification, which accepted a certain group of tubes after testing a number of randomly chosen tubes from each heat. This reduced the amount of physical testing to a small percentage of what it had been.

Early in the program it was found that although the tubes were shipped for machining after straightening them, a great deal of difficulty was being encountered after the first rough cut because the tube cambered. This was due to unrelieved stresses near the surface, set up when the tubes were cold straightened after tempering, and the partial removal of stressed metal during machining. It was therefore necessary to stress relieve the straightened tubes at a temperature about 100° lower than the tempering temperature. This solved the difficulty, and tests indicated no decrease in yield strength if the stress relief temperature was properly controlled.

Costs — Taxpayers will be interested in knowing that not only did the seamless gun tube process enable the armed forces to acquire artillery in large quantities at the time it was critically needed, and without disrupting other badly needed production, but that the saving in dollars amounted to several times the cost of the Government-owned plant where they were processed.

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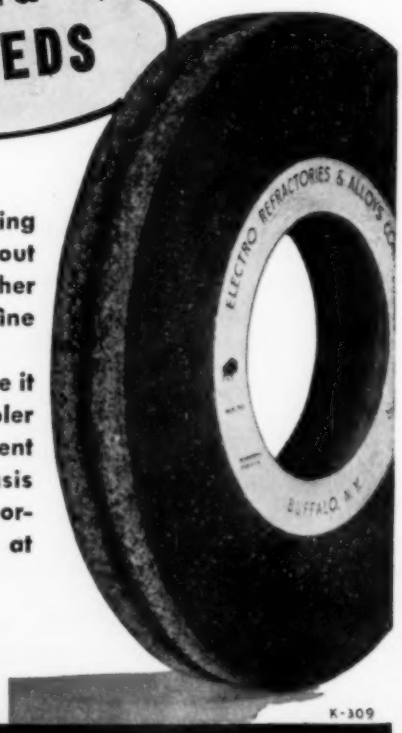

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